January 2001
NSF 01/21/EPADW395

Environmental Technology Verification Report

On-Site Sodium Hypochlorite Generation and Inactivation of Pseudomonas in Raw Drinking Water

ClorTec T-12
Exceltec International Corporation
A subsidiary of Severn Trent Services, Inc.

Prepared by

NSF International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ON-SITE SODIUM HYPOCHLORITE GENERATION USED IN DRINKING WATER TREATMENT SYSTEMS**	
APPLICATION:	**ON-SITE GENERATION OF SODIUM HYPOCHLORITE AND INACTIVATION OF PSEUDOMONAS**	
TECHNOLOGY NAME:	**CLORTEC T-12**	
COMPANY:	**EXCELTEC INTERNATIONAL CORPORATION, A SUBSIDIARY OF SEVERN TRENT SERVICES, INC.**	
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholders groups which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Treatment Systems (DWTS) pilot, one of 12 technology areas under ETV. The DWTS pilot recently evaluated the performance of an on-site hypochlorite generation system used in drinking water treatment system applications. This verification statement provides a summary of the test results for Exceltec's ClorTec T-12 System. ARCADIS Geraghty & Miller, an NSF-qualified field testing organization (FTO), performed the verification testing.

ABSTRACT

Verification testing of ExcelTec's on-site hypochlorite generation system ClorTec T-12 system was conducted for 30 days between March 6 and May 4, 2000. The system is capable of producing at least one pound of chlorine in the form of sodium hypochlorite solution containing 0.8 percent (± 0.1 percent) chlorine equivalent using 4.11 pounds of salt, 3.5 AC kilowatt hours and 15 gallons of water. In addition, the 0.8 percent sodium hypochlorite solution that the ClorTec T-12 produces on site produced a 4-log kill of *Pseudomonas aeruginosa* when dosed to achieve a concentration-time product (CT) of 50 based on actual hydraulic retention time or a CT of 26 based on a T_{10} value.

TECHNOLOGY DESCRIPTION

Sodium hypochlorite disinfection is generally used to kill bacterial contaminants in water, as well as to provide residual chlorination to drinking water. The sodium hypochlorite generation unit supplied by Exceltec for the verification project is the ClorTec T-12, which is a wall-mounted, tubular electrolytic cell. Ancillary equipment consists of a water softener that uses a small amount of potable water, salt mix tank, dual head bellows type water and brine pump, stainless steel control panel, direct current (DC) power supply, product storage tank, and a peristaltic product dosing pump with manual dose rate adjustment. A parallel system to the existing water treatment operation was established for the purposes of this verification project, consisting of the ClorTec unit and four baffled, 200-gallon tanks in series to achieve the required concentration time.

The basic principle of onsite sodium hypochlorite generation is the use of a direct current electrical field on a brine solution that results in the oxidation of the chloride found in brine, with the simultaneous and physically separated reduction of water to gaseous hydrogen, which needs to be vented to the atmosphere. While still in the electrolytic cell, all chlorine immediately reacts to form hypochlorous acid, which in turn reacts with the sodium ions to form sodium hypochlorite.

VERIFICATION TESTING DESCRIPTION

Test Site

The host site for this demonstration is the SJWD Water District Drinking Water Treatment Plant in Lyman, South Carolina, which draws water from the Middle Tyger River. The water is generally of good quality with a turbidity of less than 10 nephelometric turbidity units (NTU), hardness under 10 mg/l and TOC of approximately 2.5 mg/l. During storm events, the turbidity may rise significantly. Furthermore, the water is known to have coliforms with counts generally varying between 100 to 1,000 colony forming units (CFU) per 100 ml. Raw water was drawn at a rate of 23 gallons per minute (gpm) from a sump directly in contact with the Middle Tyger River.

Methods and Procedures

The test was divided into three tasks: 1) Equipment Disinfection Production Capabilities and Operation, 2) Microbiological Contaminant Inactivation (Challenge test), and 3) Treated Water Quality.

Under Task 1, the operation of the ClorTec T-12 was verified in terms of the concentration of sodium hypochlorite produced, the electrical power consumption per pound of available chlorine, the sodium chloride consumption per pound of available chlorine, and the volume of potable make-up water consumed per pound of available chlorine. Chlorine samples were taken twice daily and analyzed according to Standard Methods. Under this task, an assessment of the waste stream from the water softener was also performed. Parameters that were quantified in the waste stream include flow, chlorine, chloride, alkalinity, total dissolved solids (TDS), and pH, as well as heavy metals.

The objective of the microbial task was to characterize the ClorTec T-12's efficacy for inactivation of *Pseudomonas aeruginosa*. This microbe was spiked into the raw water flow for a period of time equivalent to three hydraulic retention times at a concentration of 1.9×10^6 CFUs/100 ml. *P. aeruginosa* enumeration of the samples was done using Standard Methods 9213 E. Membrane Filter Technique for *P. aeruginosa*. During the challenge testing, the total and free chlorine concentrations were verified.

The objective of the third task was to assess the impact that treatment with sodium hypochlorite generated by the ClorTec T-12 has on treated water quality. Samples were preserved, stored, shipped and analyzed in accordance with appropriate procedures and hold times, as specified by the analytical methods. Water quality parameters that were monitored during the test period include: pH, temperature, turbidity, chlorine residual (free and total), hydrogen sulfide, alkalinity, total dissolved solids (TDS), ammonia nitrogen, total organic carbon (TOC), ultraviolet absorbance (UVA) at 254 nanometer (nm), true color, iron, manganese, chloride, chlorite, chlorate, sodium, total coliforms, and heterotrophic plate count (HPC) bacteria. Analytical samples were collected from various locations within the overall treatment system. Simulated Distribution System testing for disinfection by-product (DBP) formation was conducted as a one-time event.

VERIFICATION OF PERFORMANCE

Operation and Maintenance

The ClorTec system was fully automated and capable of normal operation without manual intervention. Early in the test, the system stopped producing hypochlorite, although it continued to run. After trouble shooting with the ExcelTec technician, it was determined that the most probable cause was a failure in the programmable logic controller (PLC). A new PLC was shipped to the plant and installed by a licensed electrician. When the system was brought on-line again it operated briefly and then shut down again with a "high voltage" alarm. After about five minutes the system reset itself and started up again and ran without down-time.

ClorTec-specific maintenance consisted of periodically adding salt, as well as regenerating the water softener. Because this regeneration was not necessary during the test, the water softener was regenerated separately after the test to study the procedure and to take a sample of the waste stream from the water softener. This procedure was simple and is expected to last about 20 minutes when conducted by an experienced operator. It was noted that the ClorTec T-12 Operations Manual was well organized and clear. Routine maintenance and start-up procedures are well documented, but the description on routine operation should be expanded.

Disinfectant Production Capabilities

The ClorTec T-12 system produced and dosed chlorine constantly and effectively during the test, with the exception of the one PLC stoppage described above. The raw water was typically below the total chlorine analytical detection limit of 0.05 mg/L; six instances of raw water total chlorine concentrations above 0.05 mg/L were observed during the verification period. The average treated free and total chlorine concentrations were 1.57 and 1.68 mg/l respectively. The average finished free and total chlorine concentrations were 1.45 and 1.61 mg/l respectively. (Treated water samples are taken from contact tank 1, whereas finished water samples are taken after contact tank 4.) Generally, the bulk of measured chlorine was free chlorine. The average total chlorine concentration for the concentrated hypochlorite (ClorTec out) stream was 8.0 ± a standard deviation of 1.5 g/l, which is equal to the target production of 0.8 percent.

Potable Water, Salt, and Power Consumption

The ClorTec T-12 unit used 4.11 lb of salt and 15 gallons of potable water to produce 1 lb of chlorine. The power consumption was 3.5 kWh per lb of chlorine.

Microbiological Contaminant Inactivation

Prior to the bacterial challenge test, a tracer test was conducted on March 18 to establish the precise hydraulic retention time (HRT). According to this study, the volumetric capacity of the system was 850 gallons (3,218 liters) at a flow rate of 23 gpm or 5,223 liters per hour (l/h). The actual experimentally measured HRT was 34.1 minutes, whereas the theoretical HRT was 37 minutes.

Two challenge tests were conducted to assess the disinfection capabilities of the ClorTec T-12 system on *P. aeruginosa*. The first challenge test was performed on March 21. Due to unexpected high turbidity of the water, the test did not result in representative bacterial enumeration data. The test was repeated on May 3. Enumerations for the five positive control samples demonstrate that *P. aeruginosa* was recovered at an average concentration of 2.3×10^5 CFUs/100 ml. Enumeration for the eight valid treated samples indicated a survival of 12 CFUs/100 ml using worst-case approximations. The log reduction in bacteria acquired by inputting eight data points was 4.3.

Finished Water Quality

The average raw water pH was 7.06 ± 0.13. The ClorTec T-12 unit had a slight increasing effect on pH, which was to be expected because the hypochlorite is a base. On average, the pH of the raw water was raised by 0.33 due to hypochlorite addition. The alkalinity for the raw water was 14 ± 2.3 mg/l, whereas the alkalinity for the finished water was 17 ± 3.8 mg/l, which is what would be expected as a result of the hypochlorite dosage. The average turbidity of the raw and finished water was 9.26 and 10.76 NTU respectively.

The hypochlorite system had no apparent effect on UVA, color, iron, manganese, or TOC, because raw and finished water values are of the same magnitude. TDS values increased as a result of chlorine dosage, which was to be expected. The raw water TDS was 37.7 ± 3.2 mg/l and the finished water TDS was 47.0 ± 5.3 mg/l, thus there was an increase of approximately 9 mg/l. As far as chlorine compounds[1], the ClorTec T-12 system increases the average chloride concentration by approximately 4 mg/l (equal to 113 millimol/l). The increase in average sodium concentration was approximately 3.8 mg/l (equal to 165 millimol/l). Chlorite samples were below the detection limit for both raw water and finished water. The finished water did contain chlorate in a concentration of approximately 0.012 mg/l.

The ClorTec system performed well in eliminating coliforms. For all test days, total microfiltered coliforms were reduced from an average of 400 colony forming units (cfu)/ml to below 20 cfu/ml and the calculated log inactivation varied between 0.8 and 1.9. On March 10, no chlorine was dosed and the coliform spike in the finished water reflects this. Also on March 20, coliforms were detected in the finished water. This was the day of the storm that caused a spike in the turbidity and it may be that the debris in the raw water had a diminishing effect on the residual chlorine. The ClorTec system was effective in reducing HPC, although the value of zero was only reached on one day. The system did not perform well on March 10 and 20, due to a storm that adversely affected raw water parameters.

Halogenated byproducts were also analyzed as part of the ETV test project. In the finished water, dichloroacetic acid was 14-17 µg/l and trichloroacetic acid was 10-13 µg/l. Also approximately 7 µg/l chloroform was found in the finished water.

[1] Chloride = Cl^-; chlorate = ClO_3^-; chlorite = ClO_2^-; hypochlorite = ClO^-.

Original Signed by *E. Timothy Oppelt* *01/24/01*	*Original Signed by* *Gordon Bellen* *01/26/01*
E. Timothy Oppelt Date Director National Risk Management Research Laboratory Office of Research and Development United States Environmental Protection Agency	Gordon Bellen Date Vice President Federal Programs NSF International

NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report is not a NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents

Copies of the *ETV Protocol for Equipment Verification Testing for Inactivation of Microbiological Contaminant* dated August 1999, the Verification Statement, and the Verification Report (NSF Report # 01/21/EPADW395) are available from the following sources:
(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

1. Drinking Water Treatment Systems ETV Pilot Manager (order hard copy)
   NSF International
   P.O. Box 130140
   Ann Arbor, Michigan 48113-0140
2. NSF web site: http://www.nsf.org/etv (electronic copy)
3. EPA web site: http://www.epa.gov/etv (electronic copy)

January 2001

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ExcelTec International Corporation, a Subsidiary of Severn Trent Services, Inc. ClorTec T-12 Onsite Hypochlorite Generation System

Prepared for:

NSF International
Ann Arbor, Michigan 48105

Prepared by:

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4915 Prospectus Drive, Suite F
Durham, North Carolina 27713

Under a cooperative agreement with the U.S. Environmental Protection Agency

Jeffrey Q. Adams, Project Officer
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under Cooperative Agreement No. CR 824815. This verification effort was supported by Drinking Water Treatment Systems Pilot operating under the Environmental Technology Verification (ETV) Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for the NSF International (NSF) and the United States Environmental Protection Agency (EPA) by ARCADIS, in cooperation with Exceltec International, a subsidiary of Severn Trent Services. The test was conducted during March and April 2000 at SJWD Drinking Water Plant in Lyman, South Carolina.

Throughout its history, the EPA has evaluated the effectiveness of innovative technologies to protect human health and the environment. A new EPA program, the Environmental Technology Verification (ETV) Program has been instituted to verify the performance of innovative technical solutions to environmental pollution or human health threats. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. Verifiable, high quality data on the performance of new technologies are made available to regulators, developers, consulting engineers, and those in the public health and environmental protection industries. This encourages more rapid availability of approaches to better protect the environment.

The EPA has partnered with NSF, an independent, not-for-profit testing and certification organization dedicated to public health, safety and protection of the environment, to verify performance of small drinking water systems that serve small communities under the Drinking Water Treatment Systems (DWTS) ETV Pilot Project. A goal of verification testing is to enhance and facilitate the acceptance of small drinking water treatment equipment by state drinking water regulatory officials and consulting engineers while reducing the need for testing of equipment at each location where the equipment's use is contemplated. NSF will meet this goal by working with manufacturers and NSF-qualified Field Testing Organizations (FTO), in this case ARCADIS, to conduct verification testing under the approved protocols.

The ETV DWTS is being conducted by NSF with participation of manufacturers, under the sponsorship of the EPA Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division, Cincinnati, Ohio. It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the FTO.

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Abbreviations and Acronyms

A	ampères
AC	alternating current
CT	concentration time
CFU	colony forming units
DBP	disinfection by-product
DC	direct current
DQA	data quality audit
DQI	data quality indicator
DWTS	drinking water treatment system
ETV	Environmental Technology Verification
FOD	field operations document
FRP	fiberglass reinforced plastic
ft	feet
FTO	field test organization
gpm	gallons per minute
HAAs	haloacetic acids
HPC	heterotrophic plate count
HRT	hydraulic retention time
Hz	Hertz
IC	ion chromatography
ICP	inductively coupled plasma
kg	kilogram
kWh	kilowatt-hour
l	liter
lb	pound
LCS	laboratory control spike
LSCD	laboratory control spike duplicate
mg/l	milligrams per liter
ml	milliliter
MS/MSD	matrix spike/matrix spike duplicate
NSF	NSF International, formerly known as the National Sanitation Foundation
NTU	nephelometric turbidity units
OIT	operator interface terminal
OSHA	Occupational Safety & Health Administration
pH	minus log hydrogen concentration
PEA	performance evaluation audit
PE(S)	performance evaluation (sample)
PLC	programmable logic controller
ppm	parts per million
psi	pounds per square inch
pt/Co	referring to the ratio of platinum to cobalt in a visual color standard
QAPP	quality assurance project plan
QA/QC	quality assurance, quality control
RMP	risk management plan
RMS	Root Mean Square

RSD	relative standard deviation
SDS	simulated distribution system
TDS	total dissolved solids
TOC	total organic carbon
TSA	technical system audit
TTHMs	total trihalomethanes
U.S. EPA	United States Environmental Protection Agency
UVA	ultraviolet absorbance

ACKNOWLEDGMENTS

The Field Testing Organization, ARCADIS, was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, data collection and analysis, data management, data interpretation and the preparation of this report.

ARCADIS
4915 Prospectus Drive, Suite F, Durham NC 27713
Contact Person: Michiel Doorn

The laboratories selected for microbiological analysis and non-microbiological analytical work for this verification project were:

NSF International
789 N. Dixboro Rd.
Ann Arbor, MI 48105

Environmental Health Laboratories
110 S. Hill Street, South Bend, IN 46617
Contact Person: Paul Bowers

The Manufacturer of the Equipment was:

ExcelTec International Corporation, a subsidiary of Severn Trent Services, Inc.
1110 Industrial Blvd. Sugar Land, TX 77478
Contact Person: Jim Bess

ARCADIS wishes to thank the staff of the SJWD Drinking Water Purification Plant in Lyman, South Carolina and Mr. Doug Waldrop for all their cooperation and practical advice received during the test.

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholders groups which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF) in cooperation with the EPA operates the Drinking Water Treatment Systems (DWTS) pilot, one of 12 technology areas under ETV. The DWTS pilot evaluated the performance of the ExcelTec's ClorTec T-12 System, which is an onsite sodium hypochlorite (NaOCl) generation system used in drinking water treatment system applications. The performance claim evaluated during field testing of the system was that the system is capable of producing at least one pound of chlorine in the form of sodium hypochlorite solution containing 0.8 percent (± 0.1 percent) chlorine equivalent using less than 4 pounds of salt, less than 3 AC kilowatt hours and 15 gallons of water. In addition, the 0.8 percent (± 0.1 percent) NaOCl solution that the ClorTec T-12 produces onsite would produce a 4-log kill of *Pseudomonas aeruginosa* when dosed to achieve a concentration-time product (CT) of 50. This document provides the verification test results for ExcelTec's ClorTec T-12 System.

1.2 Testing Participants and Responsibilities

The ETV testing of the ExcelTec ClorTec T-12 System was a cooperative effort between the following participants:

NSF International
ARCADIS
ExcelTec International Corporation
SJWD Drinking Water Purification Plant
U.S. Environmental Protection Agency

The following is a brief description of each ETV participant and their roles and responsibilities.

1.2.1 NSF International

NSF is a not-for-profit testing and certification organization dedicated to public health safety and the protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in the development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF Name, Logo and/or Mark meet those standards. The EPA partnered with the NSF to verify the performance of drinking water treatment systems through the EPA's ETV Program.

NSF provided technical oversight of the verification testing. An audit of the field analytical and data gathering and recording procedures was conducted. NSF also provided review of the Field Operations Document (FOD) and this report.

Contact Information:

NSF International
789 N. Dixboro Rd., Ann Arbor, MI 48105
Contact Person: Bruce Bartley, ETV Pilot Manager
Phone: 734-769-8010
Fax: 734-769-0109
Email: bartley@nsf.org

1.2.2 Field Testing Organization

ARCADIS, an infrastructure and environmental engineering consulting firm, conducted the verification testing of the ExcelTec ClorTec T-12 System. ARCADIS is an NSF-qualified Field Testing Organization (FTO) for the ETV DWTS pilot project.

The FTO was responsible for conducting the verification testing for 30 calendar days. The FTO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The FTO was responsible for ensuring that the testing location and feed water conditions were such that the verification testing could meet its stated objectives. The FTO prepared the FOD, oversaw the pilot testing, managed, evaluated, interpreted and reported on the data generated by the testing, as well as evaluated and reported on the performance of the technology.

FTO employees conducted the onsite analyses and data recording during the testing. Oversight of the daily tests was provided by the FTO's Project Manager.

Contact Information:

ARCADIS
4915 Prospectus Drive, Suite F, Durham, North Carolina 27713
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Fax: 919 544-5690
Email: mdoorn@gmgw.com

1.2.3 Manufacturer

The treatment system is manufactured by ExcelTec International Corporation, a subsidiary of Severn Trent Services, Inc., manufacturer of onsite NaOCl generation systems for the drinking water industry.

The manufacturer was responsible for supplying a field-ready ClorTec T-12 system equipped with all necessary components including treatment equipment, instrumentation and controls and an operations and maintenance manual. The manufacturer was responsible for providing logistical and technical support as needed as well as providing technical assistance to the FTO during operation and monitoring of the equipment undergoing field verification testing.

Contact Information:

ExcelTec International Corporation
1110 Industrial Blvd., Sugar Land, Texas 77478
Contact Person: Jim Bess
Phone: 281 274-8439
Fax: 281 240-6762
Email: jbess@sanilec.com

1.2.4 Analytical Laboratories

Chlorine residual, pH, turbidity, alkalinity, hydrogen sulfide analyses, as well as coliforms and HPC counts were conducted onsite in the laboratory of SJWD:

SJWD Water District
161 Groce Road, Lyman, South Carolina 29365
Contact Person: Mr. Doug Waldrop
Phone: 864 949-2520

The SJWD onsite laboratory is certified by the state of South Carolina to perform selected drinking water analyses (Certificate No. 42012001).

Offsite analyses were performed by:

Environmental Health Laboratories
110 Hill St., South Bend, Indiana 46617
Contact Person: Paul Bowers
Phone: 219 233-4777
Fax: 219 233-8207

EHL has been issued a certificate by the State of South Carolina (Certification No. 95005001).

Pseudomonas aeruginosa analyses pertaining to the challenge test were conducted by:

NSF International
789 N. Dixboro Rd., Ann Arbor, Michigan 48105

Phone: 734 769-8010
Fax: 734 769-0109

1.2.5 U.S. Environmental Protection Agency

The EPA through its Office of Research and Development has financially supported and collaborated with NSF under Cooperative Agreement No. CR 824815. This verification effort was supported by Drinking Water Treatment Systems Pilot operating under the ETV Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

1.3 Verification Testing Site

The host site for this demonstration is the SJWD Water District Drinking Water Treatment Plant in Lyman, South Carolina. The SJWD Water District Drinking Water Treatment Plant draws water from the Middle Tyger River. The Middle Tyger River is identified as watershed 03050107-040 and is located in Greenville and Spartan Counties. The watershed occupies 64,948 acres of the Piedmont region of South Carolina. Land use/land cover in the watershed includes: 9.02 percent urban land, 23.85 percent agricultural land, 0.77 percent scrub/shrub land, 1.08 percent barren land, 64.32 percent forested land, and 0.95 percent water. There are several ponds and lakes (16-500 acres) in this watershed used for recreation, industrial, municipal and irrigation purposes. There are a total of 120.3 stream miles in the Middle Tyger River.

At the SJWD Drinking Water Treatment Plant, Middle Tyger River water is withdrawn into a flash mixer where caustic, alum and free chlorine are added. Next the water moves through 4-stage flocculators and into sedimentation basins. Following the sedimentation basins, the water being processed goes through dual media sand/anthracite filters into a clear well where addition of caustic, phosphate, and occasionally free chlorine takes place. The clear well effluent goes into a storage reservoir prior to being distributed to the public. The SJWD plant has a capacity of 6 million gallons per day (mgd).

1.3.1 Source Water

Water for the verification test at the SJWD plant is raw water, drawn directly from the Middle Tyger River. Upstream of the plant is a reservoir that is used to regulate water levels in the river. During times of draught, the reservoir levels may fall significantly and in extreme cases the water may have high amounts of manganese and cadmium in it, which had been stored in the reservoir sediments. During storm events, the turbidity of the water goes up significantly. One such event occurred during the verification testing period, pushing the turbidity up to 282 nephelometric turbidity units (NTU). On occasion, the turbidity is known to climb above 500 NTU. Typically, the turbidity is around 10 NTU or lower. A summary of feed water quality measured during the verification testing period is presented in Table 1-1 below.

Aquatic life uses are fully supported upstream based on the macroinvertebrate community, but may be threatened by a significantly increasing trend in turbidity, occurrences of zinc, and a very high concentration of cadmium measured in sediment. Aquatic life uses are fully supported

midstream but may be threatened by a significantly decreasing trend in pH. Aquatic life uses are fully supported downstream based on physical, chemical and macroinvertebrate community data. Recreational uses are not supported at any site due to fecal coliform bacteria excursions and there is a significantly increasing trend in fecal coliform bacteria concentration.

Table 1-1. Average Feed Water Quality During ETV Test Period

	Units	Average	Stand. Dev.	Minimum	Maximum	95% Conf. Interval
Chlorine Residual, (total)	mg/l	0.03	0.01	0.00	0.05	0.03, 0.04
pH		7.06	0.13	6.60	7.32	7.01, 7.67
Temperature	C	14.6	1.9	11.3	18.5	13.8, 15.3
Turbidity, (bench)	NTU	9.26	4.14	4.92	284.00	7.57, 10.95
Coliforms	#/100ml	404	445	0	Tntc*	213, 595
Heterotrophic Plate Count	CFU/ml	323	187	9	1560	132, 514
Alkalinity	mg/l	14	2	9	20	13, 15
UVA (UV 254)	1/cm	0.108	0.032	0.075	0.130	0.077, 0.139
True Color	Pt/Co units	28	20	5	40	11, 46
Ammonia Nitrogen	mg/l	<0.3	0.0	<0.3	<0.3	N/A
TOC	mg/l	1.8	0.2	1.5	2.0	1.7, 1.9
TDS	mg/l	38	3	34	40	34, 41
Iron	mg/l	1.0	0.2	0.9	1.5	0.8, 1.2
Manganese	ug/l	57	6	53	63	51, 63
Chloride	mg/l	4.3	2.7	2.7	7.4	1.2, 7.4
Chlorate	ug/l	<20	0	<20	<20	N/A
Chlorite	ug/l	<20	0	<20	<20	N/A
Sodium	mg/l	3.0	0.2	2.8	21	2.8, 3.2

* Tntc = too numerous to count
N/A = Not applicable because the standard deviation = 0

1.3.2 Pilot Effluent Discharge

The effluent of the pilot treatment unit was disposed through a two-inch pipe to a nearby man hole, that ultimately drained into the alum sludge holding pond of the plant. Because the effluent did not leave the jurisdiction of the SJWD plant, no discharge permit was required.

Chapter 2
Equipment Description and Operating Processes

The NaOCl generation unit supplied by Exceltec for the verification project is the ClorTec T-12. The cell is a tubular unit wall-mounted vertically on a PVC support board approximately 2 feet (ft) wide and 6 feet tall. Ancillary equipment consists of a small dual tank water softener with a 12 inch (in) by 12 in. foot print. A cartridge filter after the water softener ensures that no particulate matter can enter the system. A salt dissolver tank 24 in. diameter by 40 in. tall holds up to 650 pounds (lb) of salt complete with level controls. A dual head bellows type water and brine pump supply brine solution to the cell. The wall-mounted stainless steel control panel measures 24 in. by 24 in. and includes a programmable logic controller (PLC) and direct current (DC) power supply. The product storage tank is 18 in. diameter by 40 in. tall with start/stop level controller and a peristaltic product dosing pump with manual dose rate adjustment. See Figures 2-1 and 2-2.

A parallel treatment system to the existing operation was established for the purposes of this demonstration program. The system begins with a pump that draws raw water from an existing intake sump on the Middle Tyger River. This pump was adjusted to regulate the flow to 23 gpm. The water passed through the treatment set-up which consisted of: a sample tap for raw feed water sampling, a "T" for challenge test organism introduction, a "T" at which the flow from the NaOCl dosing pump of the ClorTec T-12 (see Figure 2-3) connects, and a sample tap for contactor influent. The flow then entered a contactor consisting of four baffled, 200-gallon tanks in series. Finally the flow passed an additional sample tap and was discharged to the alum settling sludge holding pond.

The basic principle of onsite NaOCl generation is the use of a direct current electrical field on a brine solution that results in the oxidation of the chloride with the simultaneous and physically separated reduction of water to gaseous hydrogen. In the electrolysis of the prepared brine solution, chlorine is generated at the anode and hydrogen is generated at the cathode according the following reactions:

$$2\,Cl^- \rightarrow Cl_2 + 2\,e^- \qquad (1)$$

$$2\,H_2O + 2\,e^- \rightarrow H_2 + 2\,OH^- \qquad (2)$$

While still in the electrolytic cell, all chlorine immediately reacts to form hypochlorous acid according to the following reaction:

$$Cl_2 + H_2O \rightarrow HOCl + HCl \qquad (3)$$

Figure 2-1. Photograph of the ClorTec T-12

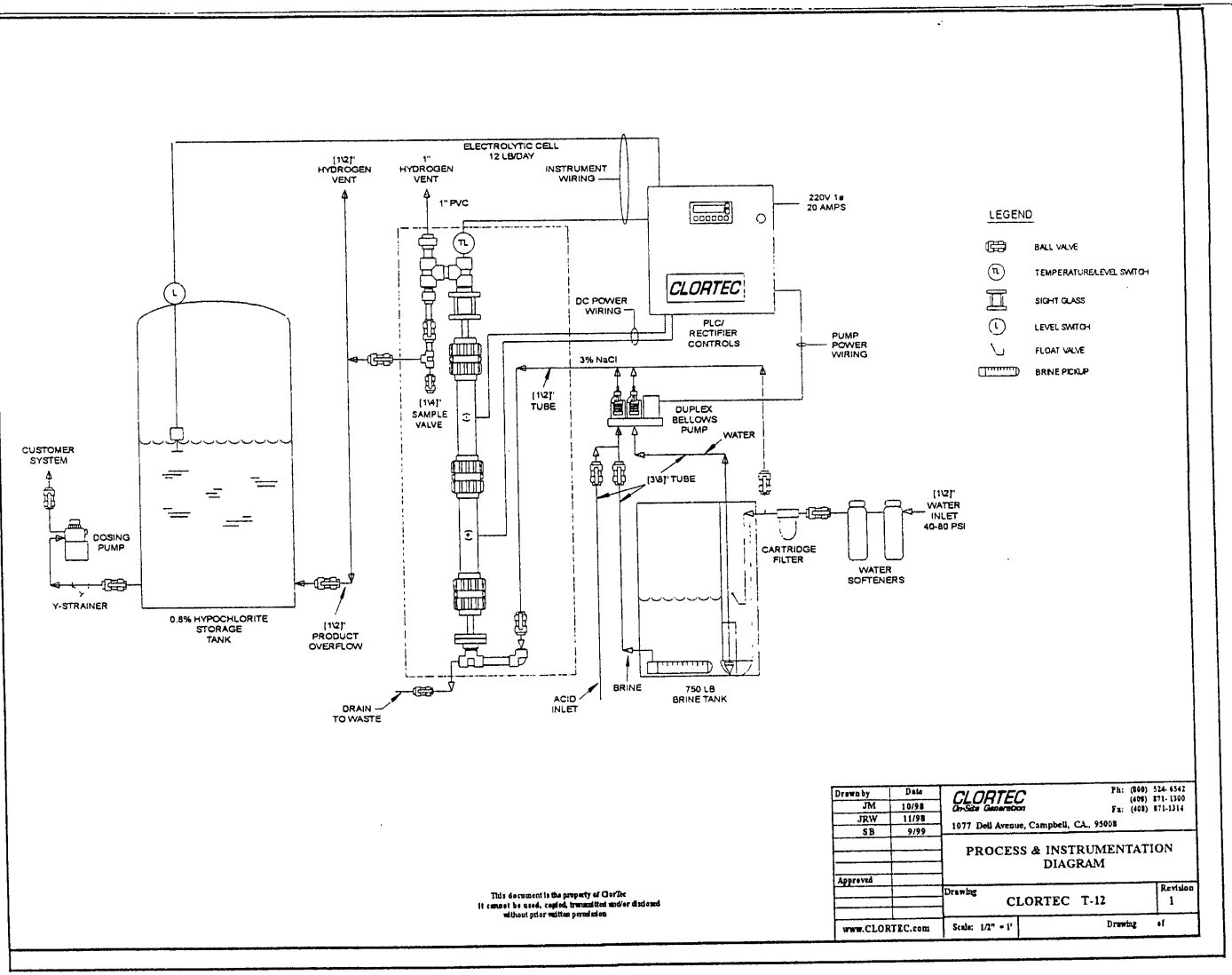


Figure 2-2. ClorTec T-12 Process and Instrumentation Diagram

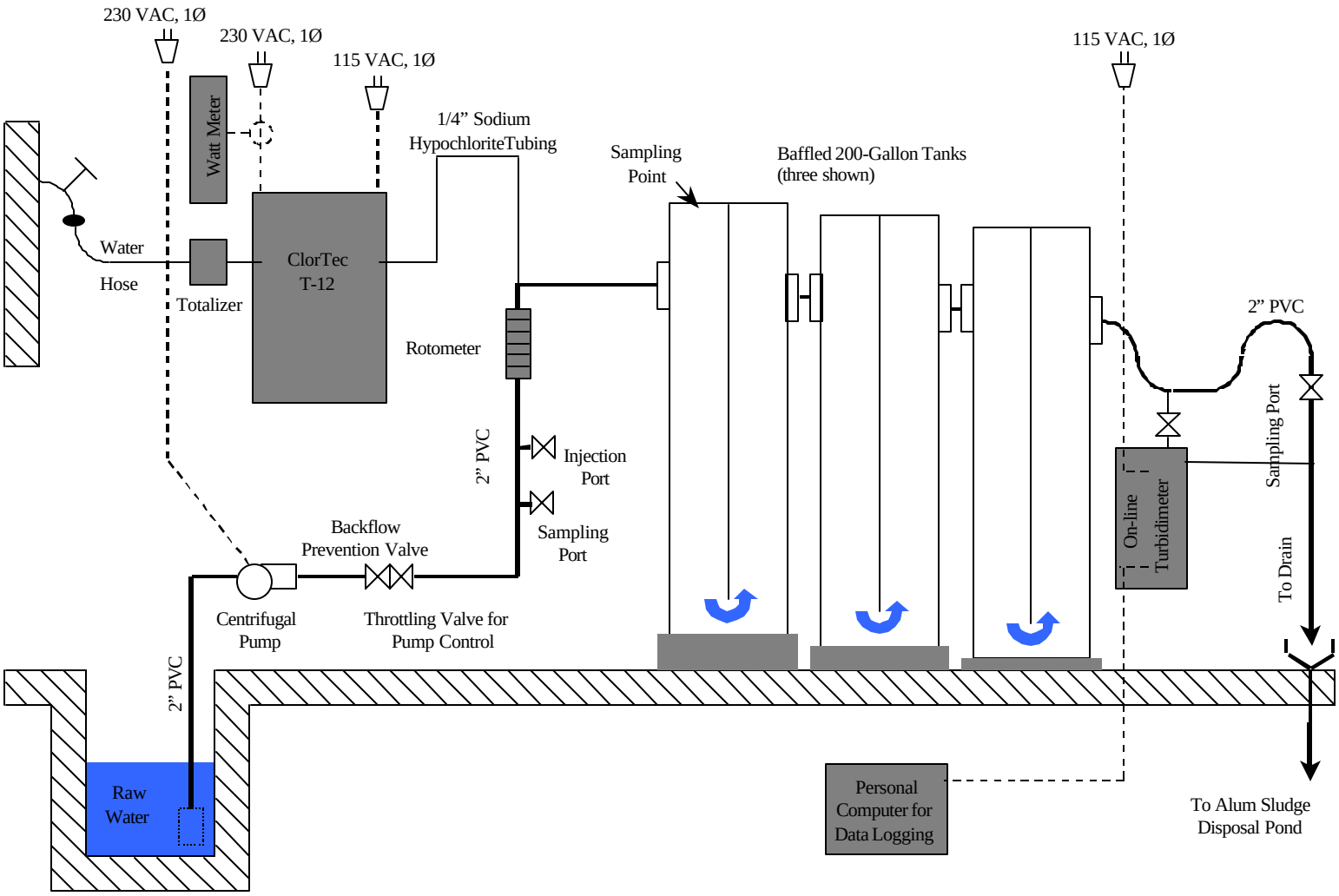


Figure 2-3. ClorTec T-12 Disinfection System Flow Diagram

While generating NaOCl, the system is operated as a batch process. To feed the NaOCl production system, softened water is required to minimize the frequency of cleaning cycles. The potable water is softened in an automatically regenerating water softener and then filtered with a cartridge filter prior to entering into a salt saturator tank where it develops into a 30 percent sodium chloride solution. Next, a proportioning pump is used to pump the softened water and a 30 percent sodium chloride solution from the salt saturator tank and the water softener at a 10:1 water to 30 percent sodium chloride solution ratio to develop a 3 percent brine solution. The 3 percent brine solution is passed through a mounted electrolytic cell. A rectifier applies a low voltage DC current to the brine passing through the electrolytic cells, producing a 0.8 percent (± 0.1 percent) NaOCl solution according to the chemical reactions provided above. The electrolytic cell unit consists of a tubular housing with PVC flanges on either end that contains paired anodes and cathodes. The electrodes consist of a proprietary coating of mixed precious metal oxides (ruthenium, iridium, and titanium) for maximum efficiency and longevity. The two anode and cathode pairs are connected electrically and hydraulically in series. Each cell unit has a water level indicator and temperature indicator to verify that water is present and that the temperature is below a factory-preset value (60° Celsius), before the cell can receive current.

The 0.8 percent (± 0.1 percent) NaOCl solution is stored in a polyethylene storage tank equipped with a level switch that monitors and controls the NaOCl level. When the NaOCl reaches a preset low level in the storage tank, the system automatically restarts to replenish the supply. A preset high level will stop the tank refilling and place the system in standby until the level in the tank again drops to the low-level set point. The only byproduct of the system is hydrogen that is safely separated from the NaOCl solution and vented outside the treatment building prior to the NaOCl entering the storage tank.

A peristaltic pump injects the NaOCl into the disinfection system. A PLC based LCD operator monitors and controls each aspect of the NaOCl generator system's operation by processing and reporting operating parameters, system and alarm conditions.

Due to logistic constraints, only one flow rate was planned for testing that is near the bottom of the practical operating range for this model. At a raw water flow rate of 23 gpm, the ClorTec T-12 will treat 33,120 gallons of raw water per day. Exceltec estimates that, if operated at is maximum capacity, the ClorTec T-12 could treat approximately 500,000 gallons of raw water per day.

Chapter 3
Methods and Procedures

The test was divided into three tasks, which are detailed below:

1. Equipment Disinfection Production Capabilities
2. Microbiological Contaminant Inactivation (Challenge test), and
3. Treated Water Quality

In addition, operation and maintenance aspects were evaluated during the ETV test period.

3.1 Task 1: Equipment Disinfection Production Capabilities

The objectives of Task 1 included the generation of data that describe the operation of the ClorTec T-12. These data and qualitative assessments were used to develop an economic assessment of operational costs. The operation of the ClorTec T-12 was verified in terms of the concentration of NaOCl produced, the electrical power consumption per pound of available chlorine, the sodium chloride consumption per pound of available chlorine, and the volume of potable make-up water consumed per pound of available chlorine. Table 3-1 includes a listing of the methods that were used and the sampling frequency.

To confirm the NaOCl concentration, two samples per day were collected from the 30-gallon NaOCl storage tank. The samples were collected at the level at which the dosing pump withdraws its NaOCl and analyzed for chlorine content according to Standard Methods for the Evaluation of Water and Wastewater 4500-Cl F. These analyses also evaluated the speciation of chlorine produced by the ClorTec T-12, because two NaOCl samples were submitted for chloride/chlorate/chlorite analysis.

A totalizing power meter was used to total the power required for a given period of time in kWh. This number was compared with NaOCl concentration and volume consumption data to determine the amount of electricity required per pound of available chlorine. The sodium chloride consumption was determined based on a comparison of the mass of sodium chloride added to the ClorTec T-12 and the NaOCl concentration and volume of solution utilized. ARCADIS also noted the amount of salt added and the salt that remained after the test to determine the sodium chloride consumption. The amount of potable water going into the ClorTec T-12 was calculated to permit a comparison of its consumption and the number of pounds of available chlorine generated. The data generated from tracking the consumption of these raw materials were used to establish equipment performance and to verify the first performance claim. This claim states that the ClorTec T-12 Onsite Hypochlorite Generators uses an unseparated, electrolytic cell to produce at least one pound of chlorine in the form of NaOCl solution containing 0.8 percent (± 0.1 percent) chlorine equivalent using less than 4 pounds of salt, less than 3 AC kilowatt hours and 15 gallons of water.

Table 3-1. Sampling and Analysis Summary

Parameter	Sampling Frequency	Test Stream	Analytical Method	Analytical Laboratory	Reporting Limit	Hold Time	Container/ Preservative
pH	1/Day	Feed, Treated, Waste	4500 H	SJWD	na	Analyze Immediately	
Temperature	1/Day	Feed, Treated, Waste	2550 B	SJWD	na	Analyze Immediately	
Raw Water Turbidity	1/Day	Feed water	2130 B	SJWD	0.1 NTU	48 hours	
Treated Water Turbidity	In-line	Treated water	Hach 1720D	na	0 – 100 NTU	na	na
Chlorine Residual	2/Day	Feed, Concentrated Sodium NaOCl Stream, Contactor Influent, Contactor Effluent, Waste	4500-Cl F	SJWD	0.05 mg/L	Analyze Immediately	250-ml poly
Hydrogen Sulfide	1/Day	Feed	SM 4500-S2-A4c	SJWD	0.1 mg/L	Not specified	100-ml glass 4 drops zinc acetate
Alkalinity	1/Week	Feed, Treated, Waste	2320 B	SJWD	10 mg/L	14 days	250-ml poly/4 °C
TDS	2/Verification Test	Feed, Treated, Waste	2540 C	SJWD	5 mg/L	7 days	250-ml poly/4 °C
Total Coliform Bacteria	5/Week	Feed, Treated	9222 B	SJWD	2 MPN/100 ml	30 hours	120-ml poly/4 °C 0.008% $Na_2S_2O_3$
HPC Bacteria	5/Week	Feed, Treated	9215 B	SJWD	1000 CFU/L	8 hours	Sterile
Ammonia Nitrogen	1/Week	Feed, Treated	4500-NH_3 G	Environmental Health Labs	0.03 mg/L	28 days	100-ml poly/4 °C pH<2 W/ H_2SO_4
TOC	4/Verification Test	Feed, Treated	5310 C	EHL	1 mg/L	28 days	Glass/4 C
UVA	1/Week	Feed, Treated	5910 B	EHL	0.01 cm^{-1}	Not to exceed 48 hrs	Glass/4 C
True Color	1/Week	Feed, Treated	2120 B	EHL	5 PCU	48 hours	250-ml poly/4 °C
Iron	2/Verification Test	Feed, Treated	200.7	EHL	50 ug/L	Analyze Immediately	250-ml poly/4 °C 2 ml HCL/100 ml
Manganese	2/Verification Test	Feed, Treated	200.7	EHL	10 ug/L	6 months	120 plastic, HNO_3 < 2
Chloride	2/Verification Test	Feed, Treated	300.0	EHL	1 mg/L	28 days	100-ml poly
Sodium	2/Verification Test	Feed, Treated	200.7	EHL	500 ug/ml	24 hours	Acid washed/4 C
Potassium	18/Tracer Test	Treated	200.7	EHL	1000 ug/L	24 hours	Acid washed/4 C
TTHMs	2/Verification Test	Feed, Treated	524.2	EHL	1 ug/L	14 days	3- 40 VOA vials
HAAs	2/Verification Test	Feed, Treated	552.1	EHL	1 ug/L	14 days	3- 40 VOA vials
Chlorite, Chlorate	2/Verification Test	Feed, Treated	300.0 B	EHL	1 mg/L	14 days, 28 days	120 plastics bottles Chlorite EDA
P. aeroginosa Enumeration	25/Bacterial Challenge Test	1/Day Feed, Balance Treated and Controls	SM 9213 E	NSF	10/100 ml	24 hours	Autoclaved 1 liter glass

na – not applicable

During the verification interval, the ClorTec T-12 was visually inspected by SJWD operators or ARCADIS staff once per 8-hour shift. These visits were documented in a bound logbook (Appendix A). The logbook was also used by SJWD operators during daily documentation of qualitative equipment performance. Under this task, an assessment of the waste stream from the water softener was also performed. Parameters that were quantified in the waste stream include flow, chlorine, chloride, alkalinity, TDS, and pH, as well as heavy metals. Table 3-1 includes a listing of the methods that were used.

3.2 Task 2: Microbiological Contaminant Inactivation

The objective of this task was to characterize the ClorTec T-12's efficacy for inactivation of *Pseudomonas aeruginosa*. The second Performance Claim states that the 0.8 percent (± 0.1 percent) NaOCl solution that the ClorTec T-12 produces onsite will produce a 4-log kill of *Pseudomonas aeruginosa* when dosed to achieve a concentration time (CT) of 50. *P. aeruginosa* was selected by ARCADIS as the bacterial challenge test organism because the *Pseudomonas* species background in the raw water was expected to be minimal and selective culture methods exist such that *P. aeruginosa* can be reproducibly cultured in the disinfected water. The laboratory that supplied the *P. aeruginosa* downstream enumeration was NSF International.

To adequately define the hydraulic retention time (HRT) that the ClorTec T-12 pilot-scale verification system represented, a tracer test was performed prior to the conduct of bacterial challenge testing. The intent of the tracer test was to provide a profile of the tracer concentration through the disinfection train as a function of time. The tracer, potassium chloride (KCl), was continuously dosed through the challenge test organism dosing port for 190 minutes. Chlorine contact chamber effluent samples were taken at 10-minute intervals throughout the 190-minute tracer test, with the first sample taken 10 minutes after testing began. The target potassium concentration in the feed water to the unit (at 23 gpm) was 30 mg/l, which is greater than 10 times the background concentration, measured to be 2.6 mg/l during the test (note that the 10-minute effluent sample yielded a potassium concentration of only 1.5 mg/l, implying that the actual feed water background potassium concentration is variable and often less than the 2.6 mg/l measured on the referenced grab sample). Grab samples of the feed background, stock solution and effluent (at 10-minute intervals) were sent to Savannah Laboratories for potassium quantification by Inductively Coupled Plasma (USEPA Method 200.7). The data results from Savannah Laboratories are summarized in Table B-1.

The protocol for the bacterial challenge is sequentially outlined below.

1) Sodium hypochlorite flow to the system was discontinued and a peristaltic pump and tubing was used to inject *P. aeruginosa* into the raw water line at 10.9 ml/minute. This rate was intended to maximize the *P. aeruginosa* concentration in the raw water while assuring that the volume of growth broth did not expire before the scheduled completion of the test. Using a calculated average concentration of 1.5×10^{10} colony forming units (CFU)/100 ml and a flow rate of 23 gpm, the theoretical *P. aeruginosa* concentration was 1.9×10^{6} CFUs/100 ml. *P. aeruginosa* was spiked into the raw water flow for a period of time equivalent to three hydraulic retention times at 23 gpm raw water flow (114 minutes). At the end of 114 minutes, ARCADIS collected three positive control samples (PC 114, PC 124, PC 134) with

10 minutes of elapsed time between sample collections. Two additional positive control samples (PC R1 and PC R2) were taken at a sample port prior to water delivery to the first contact tank after 114 elapsed minutes and before 134 elapsed minutes.

2) After the collection of positive control sample at 134 minutes of elapsed time, (Sample ID is PC 134), ARCADIS began adding NaOCl at 30.5 ml/min which is a dosing rate consistent with the dosing rate previously used during the verification interval. After the elapse of three additional hydraulic retention times (114 more minutes for a total of 248 minutes) ARCADIS began collecting nine NaOCl treated samples. These samples were collected with 10 minutes of elapsed time between them such that the test concluded after the elapse of 328 total minutes. One treated sample at 278 minutes of elapsed time was collected and analyzed in duplicate.
3) Following collection, the samples were shipped via overnight delivery to NSF International's laboratory for *P. aeruginosa* enumeration using Standard Methods 9213 E. Membrane Filter Technique for *P. aeruginosa.*

During the challenge testing, the raw water flow rate was periodically verified at the rotometer (eight times during the 328-minute test). In addition, total and free chlorine concentrations were verified in the raw water, the freshly treated water from contact tank 1 and the finished water from contact tank 4 at the time of the collection of first and last NaOCl treated samples. Samples for the analysis of *P. aeroginosa* were collected in 1-liter sample bottles previously autoclaved by ARCADIS. Immediately after collection, one milliliter (ml) of a dechlorinating solution (sterile sodium thiosulfate solution 30 g/L per Standard Methods 9060 A. 2. Dechlorination) was added as a reducing agent to prevent prolonged exposure of the *P. aeruginosa* to the effects of residual chlorine. Samples were refrigerated at 4 °C immediately after collection and shipped in a cooler maintained at or below that temperature during shipment.

3.3 Task 3: Treated Water Quality

The objective of this task was to assess the impact that treatment with NaOCl generated by the ClorTec T-12 has on treated water quality. Table 3-1 includes the treated water quality samples, the frequency with which individual analyses were performed, the analytical methodologies that were followed, and the reporting limits, holding times and sampling containers that were required. Samples were preserved, stored, shipped and analyzed in accordance with appropriate procedures and hold times, as specified by the analytical methods.

Water quality parameters that were monitored during the test period include: pH, temperature, turbidity, chlorine residual (free and total), hydrogen sulfide, alkalinity, total dissolved solids (TDS), ammonia nitrogen, total organic carbon (TOC), ultraviolet absorbance (UVA) at 254 nanometer (nm), true color, iron, manganese, chloride, chlorite, chlorate, sodium, total coliforms, and heterotrophic plate count (HPC) bacteria. Analytical samples were collected from various locations within the overall treatment system. A side stream of treated water was directed to a Hach Model 1720D in-line turbidimeter for real-time turbidity readings at the plant. Readings were taken six times per day. For the latter part of the test, the turbidimeter readings were electronically recorded through a computer data acquisition system, in order to lighten the task of the plant crew. With the exception of the in-line turbidimeter, grab samples were collected to satisfy analytical needs. When collecting a grab sample from a sample tap, sample collection

consisted of running a slow, steady stream from the sample tap, triple rinsing a dedicated sample beaker or sample container in this stream, and allowing the intended sample to flow down the side of the beaker or sample container to minimize bubble entrainment. When dipping a grab sample from a particular contact tank, sample collection consisted of triple rinsing a dedicated sample beaker with the tank water and then dipping the required sample.

Because free chlorine in aqueous solutions is unstable, the free chlorine concentration in treated water samples will decrease rapidly. Exposure to sunlight or other strong light, or agitation will accelerate free chlorine loss. For this reason, analysis of free and total chlorine samples was done at the SJWD plant laboratory immediately after sampling. Other samples analyzed at SJWD included pH, temperature, bench-top turbidity, hydrogen sulfide (H_2S), alkalinity, TDS, total coliform and HPC.

Simulated Distribution System testing for disinfection by-product (DBP) formation was conducted as a one-time event. Six samples were collected in one-liter amber bottles with Teflon-lined caps. The samples were pH adjusted to 8.0 ± 0.2 using 1M hydrochloric acid (HCl) dosed with 0.8 ± 0.1 percent NaOCl to yield a target chlorine residual of 1.0 ± 0.4 mg/l after storage. The samples were capped with zero headspace and stored for 24 hours in the dark at 20 ± 1 °C. Following incubation, the six samples were reanalyzed for chlorine residual. The two samples with chlorine residuals closest to the 1.0 ± 0.4 mg/l target were submitted for DBP testing.

3.4 Operation and Maintenance

As part of the test, operation and maintenance issues were evaluated. This subtask was very limited because the ClorTec T-12 and all its parts operate automatically. Also, no maintenance was required during the test period, with the exception of occasionally adding salt. Acid washing of the electrolytic cells is periodically required during prolonged utilization of the ClorTec T-12, but the verification test did not necessitate this procedure and ARCADIS was not requested by Exceltec to review this issue further. However, ARCADIS did report on the effectiveness of the Operation & Maintenance manual (Appendix E) whenever the operational progress required use of this manual. Comments regarding operation and maintenance were recorded in the on-site logbook (Appendix A).

Chapter 4
Results and Discussion

4.1 General Progress and Operation & Maintenance

The ClorTec T-12 unit as well as the ancillary equipment, including pump, sample ports and contact tanks, were installed on March 1 and 2, 2000. Initial test runs were started on March 3 and lasted three days. The equipment operated well and there are no noteworthy events to report from the initial test run period. The actual ETV verification test started on March 6, 2000. The last day of daily sampling was April 28 and the last round of samples for off-site analysis were collected on May 4. The actual verification period lasted 30 days. Between March 26 and April 20 the system did not operate because of a shutdown of the SJWD water plant, due to construction.

On March 8, Ms. Carol Becker of NSF performed a field inspection and Ms. Tina Beaugrand of NSF visited the plant on March 21 to audit laboratory and challenge test procedures. No deficiencies were noted during either audit. Several corrective actions were recommended which were implemented soon after inspection to the satisfaction of NSF. Both audit reports are included in Appendix C. The first bacterial challenge test was performed on March 21. At this time, the raw water had a high turbidity due to heavy rains. This did not have an effect on the operation of the ClorTec system, which continued to operate smoothly, but it did influence the analysis of the challenge test samples negatively. The challenge test was repeated on May 3 and results are included in Section 4.2. A distribution system simulation test to analyze DBPs was done on May 6 and 7.

The system was operated for a total of 725 hours including the initial runs. During the ETV test period, the system operated for 652 hours and it was down due to equipment failure and routine maintenance for 73 hours. The logbook notes and performance data sheets are included in Appendix A. Appendix D includes the collected data in processed tabular format.

During the test the raw water flow rate was set at 23 gpm. This was not always achieved because the valve in the raw water line was over-sized and had a tendency to move towards a closed position, thus constraining flow. The flow rate was checked a minimum of three times per 24 hours and adjusted, if necessary. On two occasions, the valve had shut considerably over night and the flow registered at 6 and 10 gpm, respectively at the first inspection at 8:00 a.m. The flow was adjusted at these occasions and the rotometer was cleaned as an additional measure. If these two low-flow entries are eliminated from the data set, the average flow rate was approximately 21 gpm (4,763 l/h). Because the verification test lasted 652 hours, 0.82 million gallons (3.1 million L) of raw water were treated.

4.1.1 Qualitative Operational and Maintenance Issues

The ClorTec system was fully automated and capable of normal operation without manual intervention. The verification test had two major shutdowns and one minor interruption. On day 4 (March 9) the system stopped making NaOCl, although it continued to run. After trouble shooting with the ExcelTec technician, it was determined that the most probable cause was a

failure in the PLC and the system was shut down. A new PLC was shipped to the plant and installed by a licensed electrician on March 10. When the system was brought on-line again it operated briefly and then shut down again with a "high voltage" alarm. After about five minutes the system reset itself and started up again and ran without down-time. On March 11, the system was operational again, but no data were collected due to a communications error with the weekend staff. Also, on days 10 and 22 the system was down for a few hours due to maintenance, associated with the contact tanks and piping, as well as cleaning of the rotometer. The second major shutdown was the result of construction at SJWD plant. The shutdown due to this construction lasted from March 27 to April 20. On March 13 there occurred a "run time" alarm that resulted in the aforementioned minor interruption of the system. The system was reset after which it operated smoothly again. No information is available in the manual that describes this particular alarm.

General maintenance consisted of replacing a hose at the NaOCl pump, cleaning of the rotometer, main valve and water intake, and cleaning and recalibrating the in-line turbidimeter. ClorTec-specific maintenance consisted of periodically adding salt. The ARCADIS team added one extra bag of salt during the 30-day test period. In addition, maintenance consisted of regenerating the water softener. Because this regeneration was not necessary during the test, the water softener was regenerated separately after the test to study the procedure and to take a sample of the waste stream from the water softener. This procedure was simple and lasted about an hour, but it is believed that this procedure will not take more than 20 minutes once a routine has been developed and the operator has gained experience in doing this procedure. ARCADIS recommends clearly marking the waste stream port on the softener unit.

It was noted that the ClorTec T-12 Operation Manual was well organized, but contains no section on operation and it is suggested to include a paragraph that describes routine operation even if operation requires little or no input from the operator. Also, some consideration should be given to updating the alarm descriptions, to include the "run time" alarm.

4.1.2 Disinfectant Production Capabilities (Task 1)

The ClorTec T-12 system produced and dosed chlorine constantly and effectively during the test, with the exception of the one PLC stoppage described in the previous section. Table 4-1 includes residual free and total chlorine data for treated and finished water, as well as for the concentrated NaOCl stream. (Treated water samples were taken immediately after dosing and mixing when the water enters the first contact tank; whereas finished water samples are taken after the last contact tank). All chlorine analyses were done onsite in the SJWD laboratory.

The raw water was typically below the total chlorine analytical detection limit of 0.05 mg/L. However, there were seven incidents where total chlorine in the raw water was found to be 0.05 mg/L and several other occasions where measurable total Cl was detected in the raw water with the highest concentration being 2.17 mg/L on 3/18/00. The average treated free and total chlorine concentrations were 1.57 and 1.68 mg/l respectively. The average finished free and total chlorine concentrations were 1.45 and 1.61 mg/l respectively. Generally, the bulk of measured chlorine was free chlorine. Standard deviations are included in the table but are not believed to be meaningful in the case of finished and treated water, because they reflect varying

Table 4-1. Free and Total Chlorine Concentrations

Date	Raw, Total Cl (mg/l)	Treated[1], Free Cl (mg/l)	Treated[1], Total Cl (mg/l)	Finished[1], Free Cl (mg/l)	Finished[1], Total Cl (mg/l)	ClorTec out, Free Cl (mg/l x 10,000)	ClorTec out, Total Cl (mg/l x 10,000)
6-Mar	0.03	1.72	1.75	1.82	1.85	0.69	0.82
6-Mar	**	2.04	2.00	1.78	1.86	**	**
7-Mar	0.00	2.08	1.93	1.94	1.82	0.86	0.81
7-Mar	0.02	1.78	1.82	1.78	1.94	**	**
8-Mar	0.04	1.70	2.09	1.53	1.73	**	**
8-Mar	**	1.58	1.78	1.90	1.87	0.76	0.76
9-Mar	0.03	1.66	2.01	1.82	2.04	0.76	0.86
9-Mar	**	1.61	1.93	1.39	1.61	**	**
10-Mar [2]	**	**	**	**	**	0.81	0.75
10-Mar	0.05	0.01	0.04	0.01	0.03	**	**
11-Mar [2]	**	**	**	**	**	**	**
12-Mar	**	3.40	3.70	2.00	2.40	**	**
13-Mar	0.02	1.98	1.85	1.80	1.83	0.86	0.75
13-Mar	0.05	2.18	2.12	2.51	2.44	0.78	0.68
14-Mar	0.04	1.67	1.74	1.29	1.39	0.89	0.81
14-Mar	0.03	1.05	1.19	1.02	**	0.88	0.81
15-Mar	0.05	0.88	1.08	1.36	1.57	0.83	1.03
15-Mar	0.05	2.18	2.20	1.19	1.46	0.94	0.96
16-Mar	0.04	2.06	2.00	3.30	2.86	0.77	0.74
16-Mar	0.02	1.62	1.88	1.70	1.67	0.82	0.68
17-Mar [2]	1.04	3.66	3.50	3.34	3.30	0.88	0.84
17-Mar	0.03	1.38	1.89	1.34	1.45	0.90	0.77
18-Mar [2]	2.17	1.22	1.44	1.55	1.74	**	**
18-Mar [2]	0.98	1.13	1.51	0.77	1.02	0.88	0.82
19-Mar [2]	1.18	2.20	2.20	2.45	2.11	0.34	0.34
19-Mar	0.03	0.15	0.57	0.16	2.83	1.12	0.75
20-Mar	0.03	0.03	0.15	0.24	0.79	0.75	0.81
20-Mar	0.03	1.38	1.62	1.96	2.04	1.05	1.07
21-Mar	0.04	0.05	0.07	1.12	1.34	0.82	1.05
21-Mar	0.04	0.05	0.04	0.04	0.04	**	**
22-Mar	0.04	**	**	2.20	2.20	**	**
22-Mar	0.03	0.31	1.42	1.65	1.67	0.86	**
23-Mar	0.02	1.86	1.82	1.50	1.58	0.80	0.74
23-Mar	0.04	0.77	1.02	0.84	0.98	**	**
24-Mar	0.03	2.82	1.72	1.66	1.63	0.82	0.74
24-Mar	0.05	0.31	0.58	0.46	0.63	0.90	0.84
25-Mar	0.03	1.44	1.50	2.00	1.99	1.11	0.98
25-Mar	0.04	1.04	1.19	0.63	0.85	0.82	0.80
26-Mar	0.04	2.58	2.20	2.56	2.20	0.80	0.71
20-Apr [2]	0.99	2.55	>2.20	2.71	>2.20	**	**
20-Apr	0.03	2.02	1.92	2.09	1.97	0.86	0.80
21-Apr	0.04	1.07	1.13	1.35	1.33	**	0.83
21-Apr	0.05	2.16	1.92	1.21	1.39	**	**
22-Apr	0.03	1.70	1.68	1.69	1.65	0.80	0.74
22-Apr	0.03	2.09	2.14	1.50	1.51	**	**
23-Apr	0.03	1.71	1.67	1.43	1.39	1.20	1.11
24-Apr	**	1.96	1.61	1.47	1.51	**	**
24-Apr	0.02	1.87	1.83	0.36	0.63	0.76	0.68
25-Apr	0.03	1.87	1.81	1.38	1.38	0.51	0.49
25-Apr	**	1.74	1.90	1.51	1.51	**	**
26-Apr [2]	0.15	1.40	1.58	1.35	1.38	0.74	0.76
26-Apr	**	1.61	2.04	1.12	1.57	**	**
27-Apr	0.05	2.80	3.80	1.89	1.83	0.92	0.80
27-Apr	**	1.52	1.80	1.25	1.47	**	**
28-Apr	0.03	1.32	1.43	0.03	1.38	0.74	0.69
28-Apr	**	1.79	1.78	1.34	1.46	**	**
Average	0.03	1.57	1.68	1.45	1.61	0.84	0.80
Standard Deviation	0.01	0.73	0.70	0.65	0.53	0.16	0.15
Minimum	0.00	0.03	0.04	0.03	0.04	0.34	0.34
Maximum	0.05	3.40	3.80	3.30	2.86	1.20	1.11
95% Conf. Interval	0.03, 0.04	1.37, 1.78	1.48, 1.88	1.26, 1.63	1.46, 1.76	0.78, 0.89	0.75, 0.85

[1] Treated water samples are taken immediately after dosing and mixing when the water enters the first contact tank; whereas finished water samples are taken after the last contact tank.

[2] Data not used in statistical analyses.

** not available.

parameters in the raw water that affect residual chlorine. The average total chlorine concentration for the concentrated NaOCl (ClorTec out) stream was 8.0 ± 1.5 g/l, which is equal to the target production of 0.8 percent. The total potable water consumption for the verification period was 1,161 liters (see Section 4.1.3). When this volume is multiplied by the concentration of 8.0 g/l chlorine, one arrives at 9.3 kg of chlorine that was dosed into 3.1 million liters of water. This reflects a concentration of 3.0 mg/l.

The total residual chlorine concentration of the finished water was 1.61 mg/l, therefore it can be calculated that 1.39 mg/l were absorbed by the constituents of the raw water.

On March 17 a.m., 18 a.m., and 19 a.m., and April 20 a.m., the raw water total chlorine content was higher than normal, i.e., 0.99-2.00 mg/l. The reason for this high chlorine content is that the SJWD plant was shut down several times on those dates and water from the flash mix tank drained back to the sump where the ClorTec was obtaining its raw water. On March 10 and 11 no chlorine was dosed due to the problem with the PLC. (In fact, measurements were taken on March 10 that indicate this.) The bottom rows in Table 4-1 provide statistical data including average, standard deviation, minimum maximum and 95 percent-confidence intervals, while excluding the entries for raw, treated and finished water for March 17 a.m., 18, 19 a.m., and April 20 a.m.; as well as all data for March 10 and 11, because these are considered outliers or inaccurate.

4.1.3 Potable Water, Salt, and Power Consumption

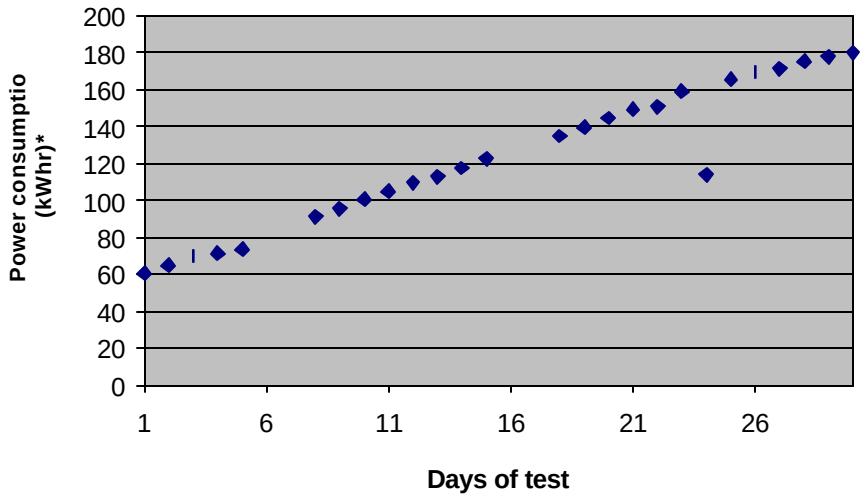
The unit consumed potable water while making NaOCl.[2] Hypochlorite generation occurred for about an hour a day and was governed by level indicators in the NaOCl storage tank. Because NaOCl production occurred infrequently and not necessarily during daytime, it was not possible to monitor the process on a regular basis. However, NaOCl from the storage tank was dosed into the water continuously. This stream was volumetrically determined daily and used to back-calculate the potable water consumption. The average NaOCl usage was 29.7 ± 7.1 ml/minute, equaling 1,161 liters (307 gallons) for the entire test. Because there are no water losses during the process and since the volume of the NaOCl is negligibly small, the quantity of potable water used by the ClorTec T-12 is also 307 gallons for the 30-day test.

The ClorTec unit consumed three 40 lb bags or 120 lb (54.43 kg) of salt (NaCl). The salt was obtained in bags from a local store and was provided by Cargill. The salt contained no impurities as stated by the material safety data sheet MSDS (Appendix B). When the ClorTec unit was shut down on March 26, some NaOCl remained in the tank. This volume of NaOCl was wasted, because it was assumed by the operator that the NaOCl would lose its strength over time. According to the datasheet entry on March 26, the level of the brine tank was 2.75 inches down, indicating there was approximately 27 gallons (102 L) in the tank. The concentration of the NaOCl was 8.0 ± 1.5 g/l, so there were 816 grams NaOCl in the tank. One mole of NaOCl equals 74.5 grams, thus there were 11 moles of NaOCl or NaCl (no chlorine loss), which equals 644 grams (1.42 lb). Consequently an equivalent of 1.42 lb of salt was wasted when the NaOCl tank was drained.

[2] Unfortunately, the totalizer that was initially installed turned out to be unsuited for the flow rate. A second electronic totalizer was ordered, but this instrument also failed to perform adequately. Therefore, the potable water use was calculated instead of totalized.

After the test the remaining brine solution in the tank was collected, dried and weighed. The remaining salt was 11.92 kg. Because 54.3 kg was added and 0.644 kg was wasted, the quantity of salt used was 41.9 kg during the full 725-hour period which includes start-up. When this amount is pro-rated for the duration of the verification test (652 hours), the quantity of salt used is 37.65 kg. On a per-hour basis, the ClorTec system consumed 57.8 g salt. 12.1 mg of salt was used per liter of treated water.

The power consumption was totalized by an Amprobe kWh meter and was relatively uniform over time (see Figure 4-1). It appears there was one misread entry on day 24. On day one of the test, the reading was 60 kWh and on day 30 the reading was 180 kWh. Consequently, according to the meter, 120 kWh was used. This number is approximately two orders of magnitude higher than expected, and when Exceltec was informed of this, they advocated additional testing to substantiate this high power consumption.



* Please see text for correct power values

Figure 4-1. ClorTec T-12 Power Meter Readings During 30-Day Test

On 7/19/2000 Mr. Ted Balk P.E. of ARCADIS and Mr. Jim Bess of Exceltec conducted a series of tests to determine if there was an error in the power meter readings, and if so, could an accurate assumption of actual power consumption be made. The original ClorTec T-12 system was re-installed and connected to the same power system as before. The original power meter was also re-installed. Because the meter had been removed from the system, it was impossible to verify that the new set up was exactly like the first set up.

A three-hour duration test was conducted by putting the system in operation and recording data from several locations periodically throughout the test. The instruments used were a hand-held Esterline Angus kW meter and Fluke Digital multimeter with Fluke True Root Mean Square RMS amp clamp. These instruments were calibrated by Inotek Technologies Corporation (see Appendix B). The Amprobe power meter readings were recorded as was actual AC current and voltage at the circuit breaker panel. A verification measurement was conducted at the location of

the power meter taps and these readings were the same as the reading at the circuit breaker panel. The actual DC voltage and current readings were read at the output of the ClorTec panel to the ClorTec unit (see Table 4-2).

Table 4-2. Detailed Voltage and Current Readings ClorTec T-12

Time	KW Meter	AC Volts	AC Amps	DC Volts	DC Amps
11:15	11.807	236.2	7.5	9.66	128
11:45	11.843	236.4	7.6	9.67	128
12:15	11.880	236.6	7.5	9.65	128
12:45	11.917	235.2	7.5	9.65	128
13:15	11.954	235.5	7.5	9.65	128
13:45	12.027	235.7	7.5	9.61	128
	Average	235.9	7.5	9.65	128

According to the Amprobe meter, power consumption was (12.027-11.807)*20=4.40 kWh, or an average of 1.47 kWh over the three hour test. The factor "20" is the factory set scaling factor.

Using the formula for AC power: AC kW=(volts*amps*power factor)/1000, we get (235.9 volts * 7.52 Amps * 0.99)/1,000 = 1.76 kW. (The power factor for this unit, as for most electronic DC power supplies is near unity, i.e., 0.99).

As a check, the DC measurements were averaged and power was calculated. DC power is simply: DC kW=(volts*amps)/1000. Thus, (9.65*128)/1,000=1.235 kW. The efficiency of this unit is expected to be between 70-75%. The measured efficiency is 1.235 KW / 1.76 KW = 70.2%, verifying that the measurements are within the expected range for the unit.

Comparing the meter readings with the direct readings and calculations, we see that the Amprobe meter is reading 1.47/1.76 = 0.835 of the direct readings. The direct readings and calculations using a calibrated hand-held meter are believed to be far more accurate than the meter, thus we assume that the meter is in error by 16.5%, and is low of the actual number. This is a surprising result, as the Amprobe meter readings during the 30-day test were approximately twice the expected numbers.

The manufacturer of the meter was contacted for additional consultation. The manufacturer's technical representative stated that the model in question was rated for 100 Amps maximum and that the readings become inaccurate below 10 Amps, with increased inaccuracy below 5 Amps. Therefore, the probable cause of the 16.5% meter error in the reading during the retest is because the current readings were below the rated minimum for the meter (7.5 Amps).

This, however, does not resolve the difference between the power meter reading and the expected power consumption for the ClorTec T-12 unit. In discussing the problem with the meter manufacturer, we were informed that there are several ways that the meter could be installed so that a reading twice the actual power consumption would be recorded. As it could not be verified how the meter was initially installed, since it had been removed and re-installed, an analysis was made of the chlorine production capabilities of the system to determine if the re-test readings would help verify the expected results.

The ClorTec T-12 is rated as producing 12 pounds of chlorine per day. From the original test data, a total of 9.3 kg (20.5 lb) of chlorine was produced during 30 days, equivalent to 310 g/day (0.68 lb/day). If the unit were running full time, it is capable of producing 12.0 lb/day. Consequently, during the 30-day test the unit was in operation 0.68 lb/12 lb*24 hrs/day = 1.36 hours/day. If power usage is 1.76 kWh per hour as calculated from the re-test, then power consumption per day would be 1.76 kWh/h * 1.36h/day = 2.39 kWh/day. Because 0.68 lb of chlorine was consumed per day, it takes 2.39/0.68= 3.51 kWh of power to generate 1 lb of chlorine.

During the 30-day test, 20.5 lb of chlorine were consumed. At this rate, 20.5 * 3.5 = 72 kWh of power would have been consumed for the test. However, the Amprobe meter registered 120 kWh (see previous page). Using the error factors discussed above, 120/(0.835 * 72) = 2.00.

In conclusion, based on the readings taken in the re-test compared to the original data, it appears that the meter installation during the 30-day test was incorrect, introducing an error factor of 2.00. In addition, an error factor of 0.835 was introduced because the Amprobe meter was oversized. Consequently, the actual power consumption was approximately 3.5 kWh per pound of chlorine. (It is noted that the power requirement calculation is based on total chlorine production over the 30-day test period and that there are sampling and other errors associated with this chlorine quantification.) Therefore, the Claim pertaining to power consumption could not be verified. Data pertaining to Performance Claim 1 are summarized in Table 4-3.

Table 4-3. Summary of Consumption Data and Chlorine Production

Parameter	Rate	For Test	Per kg of chlorine	Per lb. of chlorine
Potable water consumption	29.7 ± 7.1 ml/minute	1,161 l	125 l/kg	15 gal/lb
Salt consumption	58.6 g/hour	38.2 kg	4.11 kg/kg	4.11 lb/lb
Power consumption	Not applicable	72 kWh	7.7 kWh/kg	3.5 kWh/lb
Chlorine production	8.0 ± 1.4 g/l	9.3 kg		

The ClorTec T-12 unit used 4.11 lb of salt to produce 1 lb of chlorine. The power consumption was 3.5 kWh per lb of chlorine.

4.1.4 Waste Production

The water softener of the ClorTec system is designed to regenerate automatically during the test. Because of the low flow, this event did not occur and the regeneration sequence was manually induced after the test. The analysis of the waste stream is included below in Table 4-4. ARCADIS believes that the chemical composition of this waste stream is consistent with disposal in the sanitary sewer.

Based on a stoichiometric calculation by the manufacturer, the ClorTec T-12 will produce 0.064 cubic feet of waste hydrogen for every minute that it produces NaOCl. In its current application, the manufacturer estimated that the ClorTec T-12 would operate for 108 minutes in each 24-hour period. Using these calculated values, ARCADIS estimates daily hydrogen production at 6.9

cubic feet of hydrogen per operational day. ARCADIS has interpreted known regulatory guidelines and it is not specifically clear that hydrogen is exempted at any level without getting the case-by-case exemption. Thus, commerical installation and operation of the ClorTec T-12, where it would operate on a continuous basis, would involve notifying the pertinent regulatory agency of the expected hydrogen emissions and seeking a case-by-case exemption or permit for hydrogen emission.

Table 4-4. Results of Heavy Metal Analysis on Water Softener Regeneration Waste Stream

Analyte	Analytical Method	Concentration (µg/L)
Antimony	USEPA 200.8	< 2.0
Arsenic	USEPA 200.8	6.4
Beryllium	USEPA 200.8	< 0.2
Cadmium	USEPA 200.8	< 2.0
Chromium	USEPA 200.8	14
Copper	USEPA 200.8	1,300
Lead	USEPA 200.8	14
Mercury	USEPA 200.8	< 0.1
Nickel	USEPA 200.8	18
Selenium	USEPA 200.8	< 20.0
Silver	USEPA 200.8	< 2.0
Thallium	USEPA 200.8	< 2.0
Zinc	USEPA 200.8	830

4.2 Microbiological Contaminant Inactivation (Task 2)

Prior to the bacterial challenge test, a tracer test was conducted on March 18 to establish the precise HRT. Grab samples of the feed background, stock solution and effluent (at 10-minute intervals) were sent to Savannah Laboratories for analysis. The data results from the tracer test are summarized in Table 4-5.

The results were plotted in an F-curve, as described in many chemical engineering and reactor analysis texts (Levenspiel, 1972) and shown as Figure 4-2. The F-curve shows the percentage of tracer recovered at discrete points in time (i.e., not cumulative) in the effluent versus time after starting the continuous tracer feed. The actual hydraulic retention time was calculated as the area above the curve, per Equation 4-1 below (DiGiano, Weber, 1996).

Table 4-5. Tracer Test Data

Time (minutes)	Total K (mg/l)	F (%)
0	0	0.0%
10	1.5	5.2%
20	3.9	13.4%
30	11	37.9%
40	21	72.4%
50	24	82.8%
60	27	93.1%
70	29	100.0%
80	29	100.0%
90	29	100.0%
100	28	96.6%
110	28	96.6%
120	28	96.6%
130	28	96.6%
140	29	100.0%
150	28	96.6%
160	30	103.4%
170	29	100.0%
180	30	103.4%
190	27	93.1%

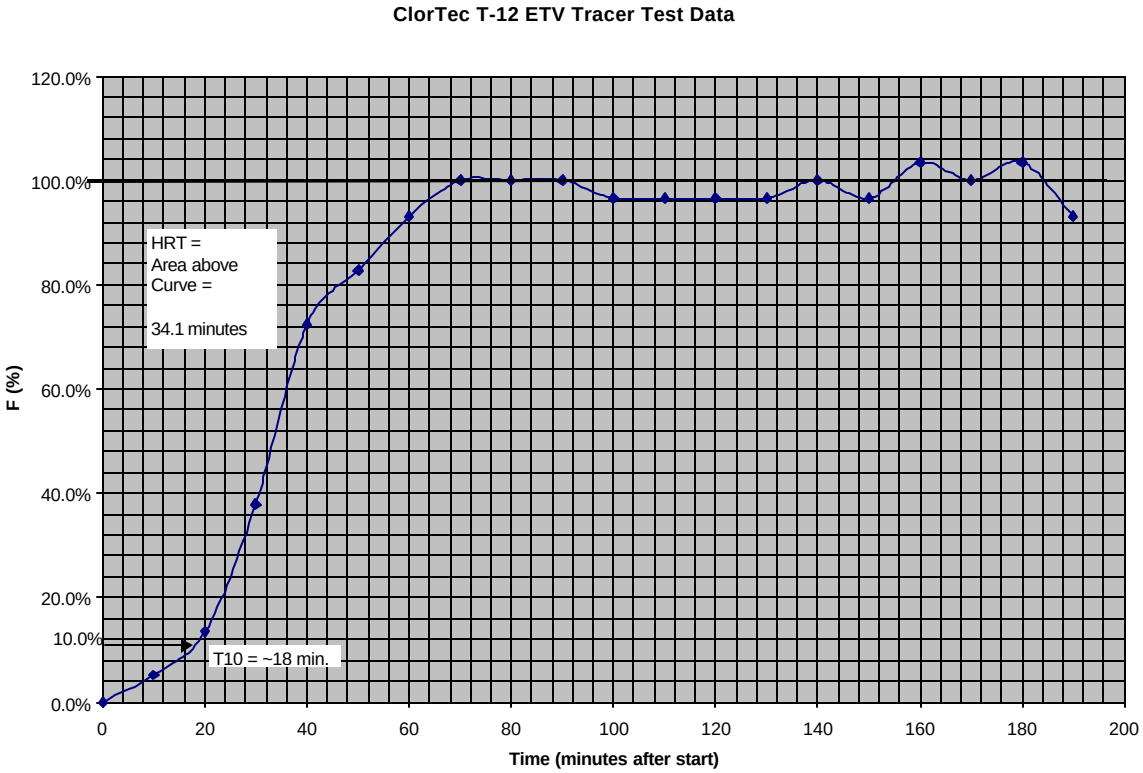


Figure 4-2. F-Curve for Tracer Test.

$$HRT = t_m = \int_0^{\infty} t \cdot dF(t) \qquad (4\text{-}1)$$

The F-curve was plotted on grid paper with a relatively fine grid resolution and the number of grid squares above the curve (up to 100 percent recovery) were manually counted. The hydraulic residence time (HRT) was then calculated per Equation 4-2.

$$HRT = 213 squares \times \frac{0.04F}{grid} \times \frac{4 \min.}{grid} = 34.1 \min. \qquad (4\text{-}2)$$

The chlorine contact chamber (CCC) for this system had a nominal capacity of 750 gallons. However, because of the location of the effluent overflow pipe and the head loss induced by piping between the three tanks employed, the actual volume of water contained in the CCC was approximately 850 gallons. At a volumetric capacity of 850 gallons and a measured flow rate of 23 gpm, the theoretical HRT for the CCC is about 37 minutes. The actual experimentally measured HRT of 34.1 minutes indicates that while there was some short-circuiting, as expected, the overall performance of the experimental CCC was quite good (within 10 percent of theoretical). The challenge testing sampling schedule should therefore be appropriate.

Per EPA Guidelines (USEPA, 1989) for calculation of CT values, the T_{10} value was also determined graphically, as shown in Figure 4-2 above. T_{10} represents the elapsed time at which the tracer concentration in the effluent is equal to 10% of the feed. As shown, the T_{10} for this system was determined to be approximately 18 minutes.

ARCADIS conducted two challenge tests to assess the disinfection capabilities of the ClorTec system on *P. aeruginosa*. The first challenge test was done on March 21. Due to unexpected high turbidity of the water, the test did not result in representative bacterial enumeration data. The method chosen required filtration which was impeded by the river sediment. The test was repeated on May 3. The results of the May 3 challenge test are found in Table 4-6. The target concentration for *P. aeruginosa* in the broth culture was 5 x 10^{10} CFUs/100 ml. Southern Testing and Research quantified *P. aeruginosa* in the whole broth in three of the eight separate 500 ml growth flasks that were combined to provide the requested one-gallon of volume. The concentrations of these three flasks were reported by Southern Research and Testing to be 1.6 x 10^{10} CFUs/100 ml, 1.7 x 10^{10} CFUs/100 ml, and 1.3 x 10^{10} CFUs/100 ml. Using these concentrations the arithmetically calculated average concentration achieved in the whole broth was 1.5 x 10^{10} CFUs/100 ml. The achievement of the target *P. aeruginosa* concentration in the broth is strictly biologically determined by the microorganism. Variance from the target whole broth concentration is only significant to the challenge test if it prevents the FTO from attaining a concentration in the treatment system that is demonstrably greater the bacterial concentration put forth in the performance statement. ARCADIS does not believe that the ClorTec challenge testing was negatively impacted by an average whole broth *P. aeruginosa* concentration that was slightly less than the initially targeted concentration because a sufficiently large concentration of *P. aeruginosa* to permit evaluation of the relevant performance statement was still technically achievable. Approximately one gallon of this cell suspension was shipped to the SJWD Water Treatment Plant on ice.

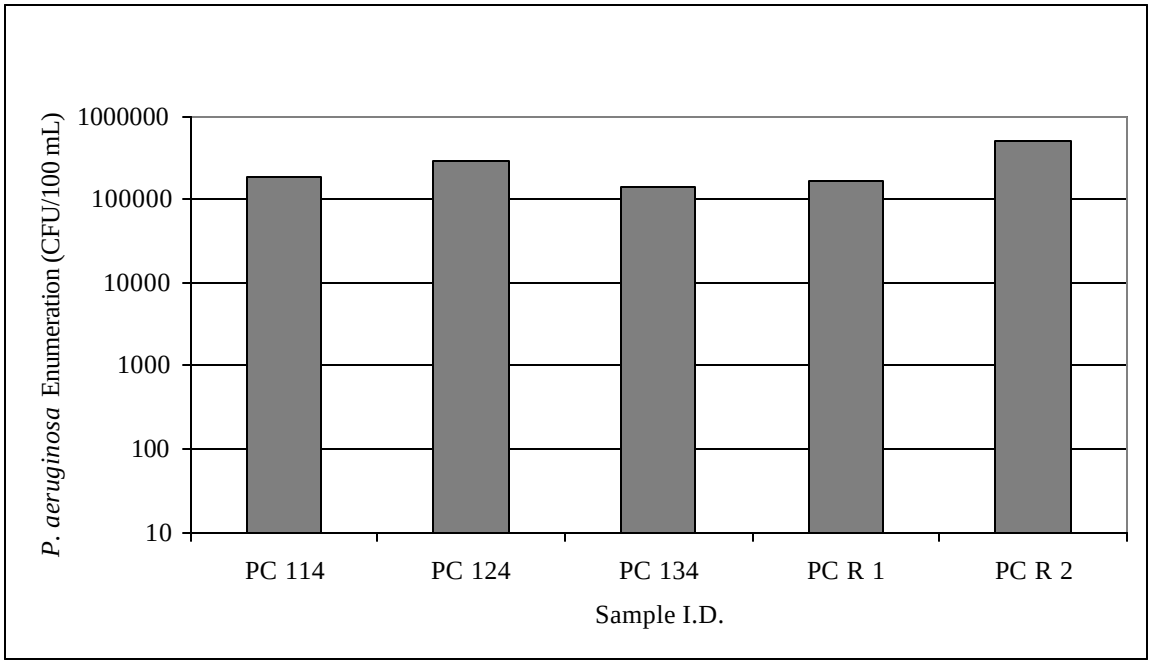
The broth was subsampled at the beginning and end of the challenge test to create two trip controls that remained on ice during the bacterial challenge-testing interval and were shipped back with the post-treatment samples to the analytical laboratory. The results of analysis on these two trip controls can be found in Table 4-6 identified as BK1 (collected at challenge test initiation) and BK2 (collected at challenge test completion). These values compare favorably with the average concentration of *P. aeruginosa* calculated above using three values provided by Southern Research & Testing. Additionally, the uninoculated raw river water was sampled at the beginning and completion of the challenge test to establish the background concentration of native *P. aeruginosa.* The analytical results for these samples can be found in Table 4-6 identified as RW pre and RW post. RW pre contained 50 viable *P. aeruginosa* cells/100 ml and RW post contained 30 viable *P. aeruginosa* cells/100 ml.

Table 4-6. ClorTec T-12 Bacterial Challenge Test Results

ARCADIS Sample I.D.	NSF Laboratory Sample I.D.	Sample Description	P. aeruginosa Concentration (CFU/100 ml)
BK1	424410	P. aeruginosa spiking broth	6.1E+10
RW Pre	424411	P. aeruginosa background in raw water	5.0E+01
PC 114	424412	Positive Control - Contact tank effluent @ 114 minutes	1.9E+05
PC 124	424413	Positive Control - Contact tank effluent @ 124 minutes	2.9E+05
PC 134	424414	Positive Control - Contact tank effluent @ 134 minutes	1.4E+05
T 248	424415	Treated Sample - Contact tank effluent @ 248 minutes	1.6E+02
T 258	424416	Treated Sample - Contact tank effluent @ 258 minutes	2.0E+01
T 268	424417	Treated Sample - Contact tank effluent @ 268 minutes	< 10
T 278 A	424418	Duplicate Treated Sample – Contact tank effluent @ 278 minutes	< 10
T 278 B	424419	Duplicate Treated Sample – Contact tank effluent @ 278 minutes	< 10
T 288	424420	Treated Sample - Contact tank effluent @ 288 minutes	< 10
T 298	424421	Treated Sample - Contact tank effluent @ 298 minutes	2.0E+01
T 308	424422	Treated Sample - Contact tank effluent @ 308 minutes	< 10
T 318	424423	Treated Sample - Contact tank effluent @ 318 minutes	< 10
T 328	424424	Treated Sample - Contact tank effluent @ 328 minutes	< 10
RW Post	424425	P. aeruginosa background in raw water	3.0E+01
PC R 1	424426	Positive Control - collected prior to entry into contact tanks	1.7E+05
PC R 2	424427	Positive Control - collected prior to entry into contact tanks	5.1E+05
BK2	424428	P. aeruginosa spiking broth	2.8E+10

The *P. aeruginosa* enumeration of the positive control samples ranged from 1.4×10^5 CFUs/100 ml to 5.1×10^5 CFUs/100 ml with a log average of 2.3×10^5 CFUs/100 ml. The control samples consisted to two populations of data. One population was sequentially collected at ten-minute intervals from the finished water leaving contact tank 4 effluent after spiking the raw water with *P. aeruginosa* for three hydraulic retention times. A second group of two samples was collected from a sample tap in the raw water feed line after the raw water was spiked with *P. aeruginosa* and had passed through an in-line mixer. These samples, collected prior to entry into the first contact tank, were previously unspecified in the FOD. Because these samples were unspecified, but believed to be useful in evaluating the challenge test data, a one-way ANOVA on the log of both populations of positive controls with a hypothesis that the data was comparable was applied. An ANOVA is an analysis of variance used to test two or more treatments to determine

whether their sample means could have been obtained from populations with the same true mean (Berthouex et. al., 1994). The results of the ANOVA revealed that the two populations of positive control data were indistinguishable with regard to *P. aeruginosa* enumeration results and thus combination of these two populations of data into a single population was statistically justifiable. The 95 percent confidence interval bounding positive control enumeration is 1.2 - 4.4 x 10^5 CFUs/100 ml with four degrees of freedom. Figure 4-3 is a graphic portrayal of the positive control sample enumerations. Figure 4-4 shows the mean of the positive control enumerations. Additionally, a statistically calculated 95 percent confidence interval is displayed on Figure 4-4. The calculations for the confidence interval will be made available separately.



PC 114 = positive control @ 114 minutes
PC 124 = positive control @ 124 minutes
PC 134 = positive control @ 134 minutes
PC R1 = 1st sample collected prior to Contact Tank #1 collected @ ~ 128 minutes
PC R2 = 2nd sample collected prior to Contact Tank #1 collected @ ~ 137 minutes

Figure 4-3. Bar Graph of Bacterial Challenge Test Positive Control Samples

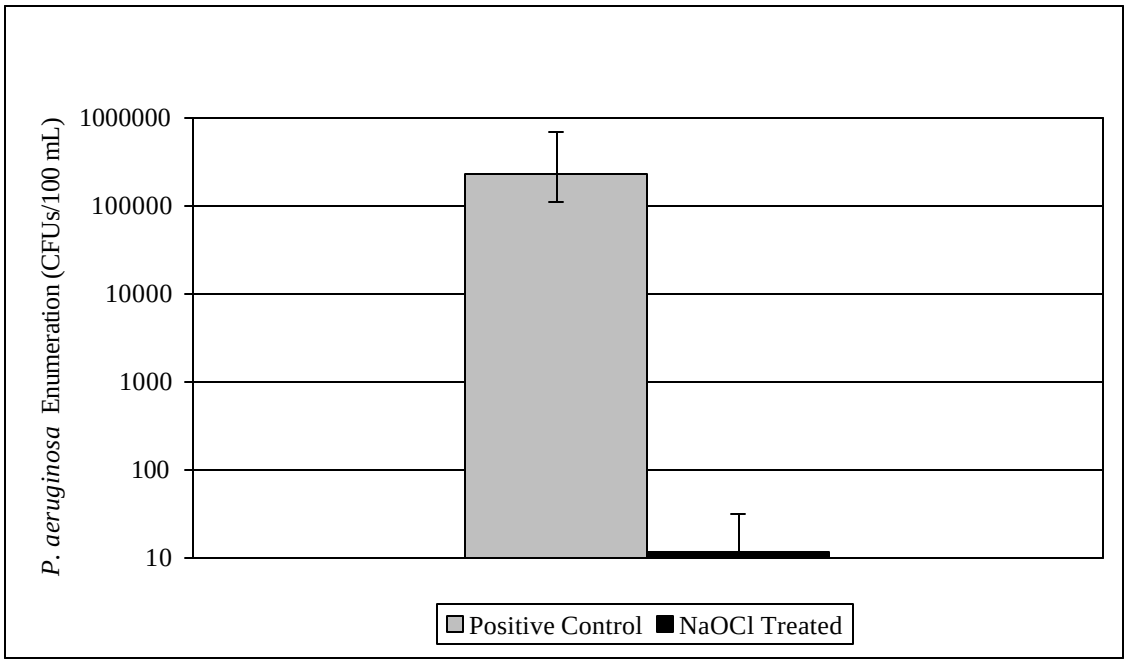


Figure 4-4. Mean Enumeration Values for Positive Control and Sodium Hypochlorite Treated Samples

The *P. aeruginosa* enumeration of the treated samples ranged from below detection limits (<10 CFUs/100 ml) to 160 CFUs/100 ml. In order for errors to be considered conservative, samples reported as being less than the detection limit were treated as if they contained 10 CFUs/100 ml. Using the variance obtained from the positive controls, 97.5 percent of enumerations should be less than 50 CFUs/100 ml. Only Sample T 248 falls above this calculated confidence interval. If T 248 is included in the statistical analysis the *P. aeruginosa* challenge test results show that the Clortec T-12 system is capable of a 4-log kill of *P. aeruginosa* at a CT value of 50 based on actual hydraulic retention time (34.1 minutes) or a CT of 26 based on the T_{10} value (18 minutes). Enumerations for the five positive control samples (PC 114, PC 124, PC 134, PC R 1, and PC R 2) demonstrate that a *P. aeruginosa* was recovered at a log-average concentration of 2.3 x 10^5 CFUs/100 ml. Enumeration for the nine NaOCl treated samples indicated a survival of 16 CFUs/100 ml using worst-case approximations. The log removal of bacteria is calculated below.

$$\text{log removal of } P.\ aeruginosa = \log_{10}\left[\frac{\left(CFU/ml\right)_{feedwater}}{\left(CFU/ml\right)_{effluent}}\right]$$

$$\text{log removal of } P.\ aeruginosa = \log_{10}\left[\frac{2.3x10^{5}\,CFU/ml}{1.6x10^{1}\,CFU/ml}\right]$$

log removal of *P. aeruginosa* = 4.2

Inspection of the results for NaOCl treated samples indicates that the first sample enumeration (T 248) with a concentration of 160 CFUs/100 ml is outside of the predicted error bars for the

analysis. As stated, earlier statistical analysis suggests that 97.5 percent of enumerations should be less than 50 CFUs/100 ml. A technical rationalization for the elimination of the T 248 data point exists. ARCADIS began adding NaOCl 134 minutes into the challenge test after collecting the last positive control sample. Sample T248 was collected 248 minutes into the challenge test. Subtracting 134 minutes from 248 minutes yields 114 minutes or exactly three hydraulic retention times. Although it is convention to assume that three hydraulic retention times is an adequate interval to establish steady state conditions, ARCADIS believes that, in this instance, the establishment of steady state with regard to NaOCl concentration in contact tank 4 could have been incomplete at 248 minutes into the test when the first treated sample (T 248) was collected. The system appears to be indistinguishable from steady state by the time the second treated sample was collected at 258 elapsed minutes. Enumeration results from the remaining eight treated samples can be used to calculate a log average concentration of 12 CFUs/100 ml. The large proportion of non-detects in treated sample enumeration makes an estimate of variance problematic when applied to an assumed log normal distribution. Once again, using the variance obtained from the positive controls, the upper boundary for the 95 percent confidence interval is 20 CFUs/100 ml. Figure 4-5 is a graphic portrayal of the NaOCl treated sample enumerations for *P. aeruginosa*. Figure 4-4, referenced earlier in the last paragraph, shows the mean of the NaOCl treated bacterial enumerations and a statistically calculated 95 percent confidence interval for an upper boundary.

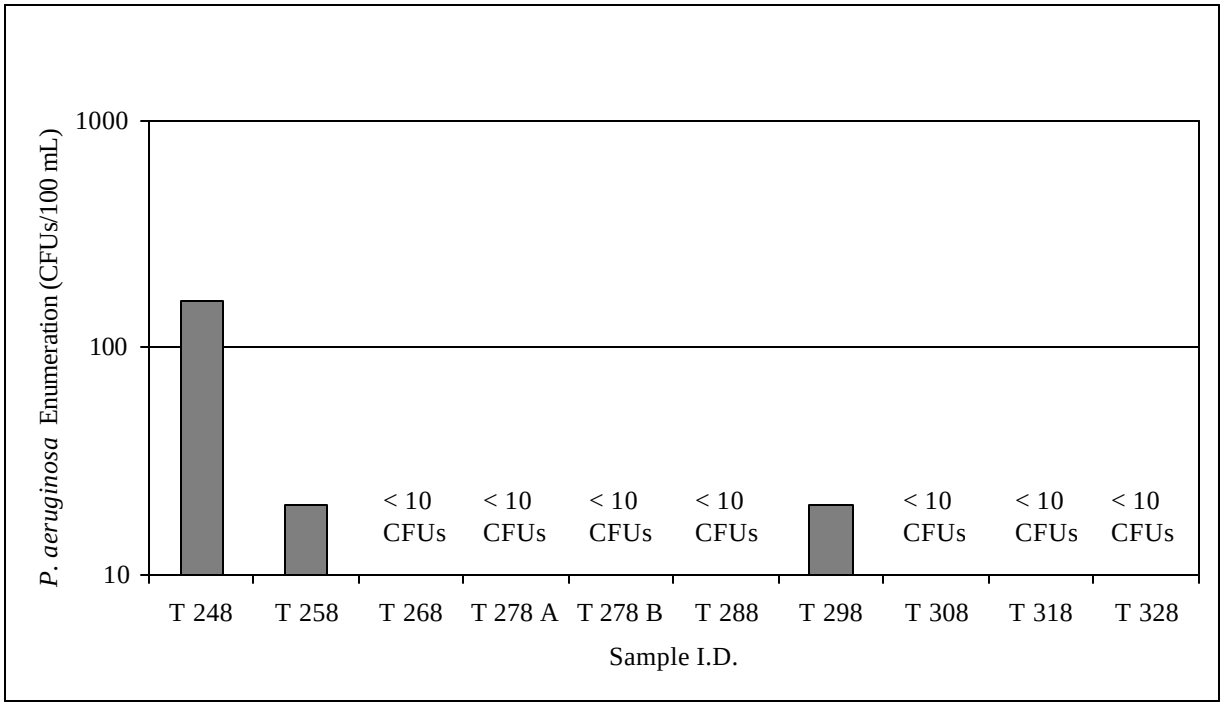


Figure 4-5. Bar Graph of Bacterial Challenge Test – Sodium Hypochlorite Treated Samples

The results of the *P. aeruginosa* challenge test show that the ClorTec T-12 system is capable of a 4-log kill of *P. aeruginosa* at a CT value of 50 based on actual hydraulic retention time or a CT of 26 based on the T_{10} value. Enumerations for the five positive control samples (PC 114, PC 124, PC 134, PC R 1, and PC R 2) demonstrate that *P. aeruginosa* was recovered at a log-average concentration of 2.3×10^5 CFUs/100 ml. Enumeration for the eight valid treated

samples indicated a survival of 12 CFUs/100 ml using worst-case approximations. The log reduction in bacteria acquired by inputting 8 data points and eliminating the T 248 data point is given below.

$$\text{log removal of } P.\ aeruginosa = \log_{10}\left[\frac{\left(CFU/ml\right)_{feedwater}}{\left(CFU/ml\right)_{dis.effluent}}\right]$$

$$\text{log removal of } P.\ aeruginosa = \log_{10}\left[\frac{2.3x10^{5}\ CFU/ml}{1.2x10^{1}\ CFU/ml}\right]$$

log removal of *P. aeruginosa* = 4.3

As mentioned above, the NaOCl dose rate during the challenge test was 30.5 ml/min. This dosing rate is typical of the dosing rate generally employed during the rest of the verification interval. Using the free chlorine concentrations found in Table 4-7 the CT values calculated are much lower than 50. The calculated CT value using actual hydraulic retention time (34.1 minutes) after 248 minutes of elapsed time is 0.68. The calculated CT value using actual hydraulic retention time after 328 minutes of elapsed time is 1.36. ARCADIS contends that these CT values are artificially depressed by the simultaneous injection of the organic material associated with the *P. aeruginosa* growth broth. ARCADIS contends that the nonbiological organic compounds present in the growth broth consumed substantial NaOCl leading to the free and total chlorine results presented in Table 4-7. Despite the resultant, depressed CT values calculated for the challenge test, the ClorTec T-12 challenge test data support a 4-log reduction in *P. aeruginosa* during the test.

Table 4-7. Results of Total and Free Chlorine Testing during Bacterial Challenge Testing

	248 Minutes of Elapsed Time		328 Minutes of Elapsed Time	
Sample Description	Free Chlorine (mg/L)	Total Chlorine (mg/L)	Free Chlorine (mg/L)	Total Chlorine (mg/L)
Deionized Water Blank	0.00	0.05	Not Performed	Not Performed
Raw Water	0.00	0.03	0.00	0.03
Treated Water (Contact Tank 1)	0.42	1.38	1.11	1.80
Finished Water (Contact Tank 4)	0.02	1.12	0.04	1.12

4.3 Finished Water Quality (Task 3)

This section presents results for water quality data that were collected during the test. Daily raw water and finished water levels of pH, temperature and turbidity are reflected in Table 4-8.

Table 4-8. Daily pH, Alkalinity, Temperature and Turbidity for Raw and Finished Water

Date	pH Raw	pH Finished	Alkalinity Raw (mg/l)	Alkalinity Finished (mg/l)	Temp. Raw (°C)	Temp. Finished (°C)	Turbidity Raw (bench) (NTU)	Turbidity Fin (in-line) (NTU)
6-Mar	7.19	**	14	**	12.5	13	6.0	**
7-Mar	7.06	7.12	15	**	13.1	13.1	5.8	6.35
8-Mar	7.07	**	14	**	14.5	14.5	6.0	6.25
9-Mar	7.20	**	14	**	15.0	15.0	6.20	8.95
10-Mar	7.29	7.10	14	**	14.0	14.0	17.60	15.64
11-Mar	6.96	**	13	**	17.7	**	10.63	8.22
12-Mar	**	7.18	14	**	**	**	**	12.02
13-Mar	7.32	7.32	14	**	11.5	11.5	6.35	6.73
14-Mar	7.10	7.08	12	16	11.25	11.0	5.62	5.83
15-Mar	7.01	7.04	**	**	12.0	12.0	5.50	4.38
16-Mar	7.13	7.42	**	**	14.0	14.0	5.64	12.79
17-Mar	7.04	7.35	14	**	13.5	14.0	16.80	23.51
18-Mar	10.12	10.37	**	**	14.0	14.0	**	9.41
19-Mar	9.66	9.4	**	**	13.0	13.0	4.92	6.92
20-Mar*	6.60	6.72	**	**	12.0	12.0	282	84.09
21-Mar*	6.92	9.37	**	**	13.0	13.0	68.8	72.09
22-Mar*	7.06	7.04	9	10	16.0	16.0	25.8	28.05
23-Mar	7.02	6.99	16	16	15.5	15.5	17.90	18.30
24-Mar	6.96	6.94	16	17	15.5	16.5	15.80	16.49
25-Mar	7.08	7.07	**	**	15.0	15.0	22.4	18.48
26-Mar*	6.95	7.52	**	**	17	17	44.7	25.16
20-Apr	7.12	7.27	12	17	18.0	18.0	6.57	8.26
21-Apr	7.08	7.08	13	16	18.5	18.0	9.77	9.38
22-Apr	7.07	7.11	**	**	17.0	17.0	9.37	**
23-Apr	7.08	7.05	**	**	17	17	8.57	**
24-Apr	7.13	7.02	20	18	16.5	16.5	8.12	7.60
25-Apr	7.03	9.03	17	16	16.0	15.5	12.70	12.78
26-Apr	7.10	7.12	**	**	15.5	15.5	8.85	10.94
27-Apr	6.99	9.12	15	25	15.5	15.5	9.40	8.24
28-Apr	6.98	6.97	**	**	16.0	16.0	8.84	10.05
Average	7.06	7.39	14	17	14.6	14.8	9.26	10.76
Standard Dev.	0.13	0.73	2.3	3.8	1.9	1.9	4.14	4.85
Minimum	6.60	6.72	9	10	11.3	11.0	4.92	4.38
Maximum	7.32	10.37	20	18	18.5	18.0	284	84.00
95% Confidence Interval	7.01, 7.67	7.10, 7.67	13, 15	14, 19	13.8, 15.3	14.1, 15.6	7.57, 10.95	8.78, 12.74

** no data available

* Turbidity data excluded on these days, because of high turbidities due to storm events

The average raw water pH was 7.39 with a standard deviation of 0.73. Minimum and maximum values for raw water pH were 6.72 and 10.73 respectively. The high pH value was the result of a shut down of the SJWD plant where water from the flash mixers drained into the sump where the ClorTec water intake was located. This occurred on March 18, 19, 21, and April 25 and 27. The ClorTec T-12 unit had a slight increasing effect on pH, which was to be expected because the NaOCl is a base. On average, the pH of the raw water was raised by 0.33, due to NaOCl addition.

The alkalinity for the raw water was 14.2 ± 2.3 mg/l, whereas the alkalinity for the finished water was 16.8 ± 3.8 mg/l, which is what would be expected as a result of the NaOCl dosage. The water was further sampled daily, and later weekly, for H_2S. All readings for H_2S were below the detection limit of 5 µg/L.

During the course of the test, the raw water temperature increased from 11.3 to 18.5 °C. The finished water temperature was usually within less than two decimal points different. Any effect of the unit on temperature can probably be attributed to the influence of ambient temperature on the water going through the contact tanks, which took about 34 minutes. During the test, the average temperature was 14.7 °C.

The average turbidity of the raw and finished water was 9.26 and 10.76 NTU respectively. Very high values are associated with the storm on March 20-22 which have not been included in the statistical analyses. For example, on March 20 the turbidity climbed to 282 NTU. Also, on March 26, there was a turbidity spike that was excluded. The finished water turbidities are averages of six readings per day, whereas the bench turbidity was measured only once per day, so a direct comparison may not be accurate because of diurnal fluctuations. In addition, the in-line turbidity was not able to register above 100 NTU, therefore, the high values from this instrument should not be deemed accurate. The inaccuracy of the statistical turbidity data are illustrated by the high standard deviations of over four NTU, as compared to averages of around 10 NTU. A comparison of the average values for raw and finished water turbidity indicate a slight increase in the finished water. This may have been because of formation of solids as a result of chlorine dosage. On the other hand, the operators noted that some sediment was deposited in the contact tanks, implying that the passing water would be becoming clearer. Because of the high standard deviations, it would not be appropriate to attach any conclusions to this finding.

Table 4-9 includes data for UVA, true color, ammonia nitrogen, TOC, TDS, iron, manganese, chloride, chlorate, chlorite, and sodium. Samples were collected in March and April. A fifth set of samples was collected on May 4 during the second challenge test. The NaOCl system had no apparent effect on UVA, because raw and finished values were the same. UVA for raw and finished water varied between 0.073 and 0.151 cm^{-1}; the highest value of 0.151 cm^{-1} was registered on March 22, two days after the storm, while the turbidity was still high (26 NTU). The color of the raw water was 40 pt/Co (referring to the ratio of platinum to cobalt in a visual color standard) with one low value of 5 pt/Co on March 17. There is a corresponding dip in the finished water reading for that date. The reason for these low readings is unknown. With the possible exception of the March 17 readings, the ClorTec T-12 system had no significant effect on color.

Ammonia nitrogen was not detected in raw nor finished water. The ClorTec T-12 had no apparent effect on iron, manganese, or TOC, because raw and finished water values are the same. TDS values increased as a result of chlorine dosage, which was to be expected. The raw water TDS was 37.7 ± a standard deviation of 3.2 mg/l and the finished water TDS was 47.0 ± a standard deviation of 5.3 mg/l, thus there was an increase of approximately 9 mg/l.

Table 4-9. Miscellaneous Test Data

Parameter	Unit	13-Mar	17-Mar	22-Mar	24-Apr	4-May
UVA (UV 254), raw	1/cm	0.075	0.085	0.131	**	0.13
UVA (UV 254), finished	1/cm	0.073	0.08	0.151	**	0.10
True Color, raw	pt/Co	40	5	40	40*	40
True Color, finished	pt/Co	35	25	40	40*	37
Ammonia Nitrogen, raw	mg/l	<0.3	<0.3	<0.3	<0.3	<0.3
Ammonia Nitrogen, finished	mg/l	<0.3	<0.3	<0.3	<0.3	<0.3
TOC, raw	mg/l	1.5	1.6	2.0	1.8	1.9
TOC, finished	mg/l	1.5	1.7	2.0	1.8	1.9
TDS, raw	mg/l	**	40	**	39	34
TDS, finished	mg/l	**	49	**	51	41
Iron, raw	mg/l	**	1.3	1.5	0.9	0.9
Iron, finished	mg/l	**	1.3	**	1.0	1.0
Manganese, raw	µg/l	**	63	**	54	53
Manganese, finished	µg/l	**	60	53	51	52
Manganese, NaOCl stream	µg/l	**	<0.2	**	<0.2	**
Chloride, raw	mg/l	**	7.4	**	2.7	2.7
Chloride, finished	mg/l	**	9.4	**	9.0	6.2
Chloride, NaOCl stream	mg/l	**	16,000	**	16,000	**
Chlorate, raw	µg/l	**	<20	**	**	<20
Chlorate, finished	µg/l	**	120	**	150	100
Chlorate, NaOCl stream	mg/l	**	310	**	**	**
Chlorite, raw	µg/l	**	<20	**	**	<20
Chlorite, finished	µg/l	**	<20	**	<20	<20
Chlorite, NaOCl stream	µg/l	**	<20,000	**	**	**
Sodium, raw	mg/l	**	3.1	2.8	3.1	21
Sodium, finished	mg/l	**	6.6	**	7.9	5.75
Sodium, NaOCl stream	mg/l	**	15,000	**	11,000	**

* samples analyzed beyond holding time

** no data available

As far as chlorine compounds[3], the ClorTec T-12 system increases the average Cl^- concentration by approximately 4 mg/l (equal to 113 millimol/l). The increase in average sodium concentration was approximately 3.8 mg/l (equal to 165 millimol/l). (The high value of 21 mg/l for sodium on May 4 was excluded. No explanation could be found as to why this value is an order of magnitude higher than the three other values. It is unlikely that the SJWD drained NaOCl into the raw water sump, because the chlorite sample was below the detection limit.) Consequently, approximately 113 millimol/l of NaCl was added to the stream, equaling 6.6 mg/l of salt. Chlorite samples were below the detection limit for both raw water and finished water. The finished water did contain chlorate in a concentration of approximately 120 µg/l or 0.012 mg/l.

Table 4-10 includes data for coliforms and HPC. The ClorTec system performed well in eliminating coliforms. For all test days, total coliforms were reduced to below 20 cfu/ml and the calculated log activation varied between 0.8 and 1.9[4]. On March 10, no chlorine was dosed and the coliform spike in the finished water reflects this. Coliform data for March 10 are nonsensical and seem almost to be reversed with low coliform concentrations in the raw water and coliforms that are too numerous to count in the finished water. Though several possible explanations exist

[3] Chloride = Cl^-; chlorate = ClO_3^-; chlorite = ClO_2^-; hypochlorite = ClO^-.

[4] Statistical analysis was not performed, because values are dependent on raw water data, which were highly variable.

for this nonsensical day of coliform data exist, ARCADIS is unsure of the mechanism which created the March 10 coliform results. Also on March 20, coliforms showed up in the finished water. This was the day of the storm that caused a spike in the turbidity and it may be that the debris in the raw water had a diminishing effect on the residual chlorine, although this is not evident from Table 4-1. The ClorTec system was effective in reducing HPC, although the value of zero was only reached on one day. Again, the system did not perform well on March 10 and 20, due to the storm. In addition, the HPC is high for March 13 indicating that disinfection was not adequate. On this day, there is an entry in the logbook that indicates a "run time" alarm and the associated shutdown of the system. The system was reset after which it operated smoothly again. No information is available in the manual that describes this particular alarm.

Table 4-10. Data for Coliforms and Heterotrophic Plate Counts

	Raw Water		Finished Water		Calculated Log Inactivation	
Date	Total Coliforms #/100 ml	Total Heterotrophic Plate Count CFU/ml	Total Coliforms #/100 ml	Total Heterotrophic Plate Count CFU/ml	Total Coliforms	Total Heterotrophic Plate Count
3/6/00	120	**	< 20	**	0.78	**
3/7/00	180	44	< 20	< 30	0.95	0.2
3/8/00	180	81	< 20	< 30	0.95	0.4
3/9/00	250	59	< 20	< 30	1.1	0.3
3/10/00	< 20	204	tntc	208	**	0
3/11/00	**	**	**	**	**	**
3/12/00	**	**	**	**	**	**
3/13/00	350	227	< 20	106	1.2	0.3
3/14/00	600	127	< 20	< 30	**	0.6
3/15/00	300	144	< 20	< 30	1.2	0.7
3/16/00	< 20	< 30	< 20	< 30	**	**
3/17/00	< 20	73	< 20	< 30	**	0.4
3/20/00	tntc	> 500	**	316	**	**
3/21/00	1500	1560	< 20	< 30	1.9	1.7
3/22/00	1450	742	< 20	< 30	1.9	1.4
3/23/00	800	636	< 20	< 30	1.6	1.3
3/24/00	700	583	< 20	< 30	1.5	1.3
4/20/00	< 20	< 30	< 20	< 30	**	**
4/21/00	< 20	32	< 20	< 30	**	0
4/24/00	500	255	< 20	< 30	1.4	0.9
4/25/00	750	520	< 20	32	1.6	1.2
4/26/00	300	334	**	< 30	**	1.0
4/27/00	200	309	< 20	84	1.0	0.6
4/28/00	300	**	< 20	**	1.2	**

tntc = too numerous to count
** = no data available
log inactivation was calculated using the formula on page 26
Note: when the test result was below the detection limit, the detection limit was assumed in the log inactivation calculation.

Total trihalomethanes (TTHMs) and haloacetic acids (HAAs) were also analyzed as part of the ETV test project and the results are included in Table 4-11. In the finished water, dichloroacetic acid was 14-17 µg/l and trichloroacetic acid was 10-13 µg/l. Also approximately 7 µg/l chloroform was found in the finished water.

Table 4-11. TTHMs and HAAs

(µg/l)	Raw 17-Mar	Raw 24-Apr	Raw 4-May	Fin.[1] 17-Mar	Fin. 24-Apr	Fin. 4-May	NaOCl[2] 17-Mar	NaOCl 24-Apr
bromoform	<0.1	<0.1	<0.1	**	<0.1	<0.1	6.8	7.3
chloroform	<0.1	<0.1	<0.1	8.6	6.0	6.0	250	340[3]
dibromochloromethane	<0.1	<0.1	<0.1	0.2	0.1	0.1	23	21
bromodichloromethane	<0.1	<0.1	<0.1	1.8	1.3	1.4	40	38
bromochloroacetic acid	<0.1	<1.0	<1.0	1.4	1.3	1.4	m.i.	m.i.
dichloroacetic acid	<0.1	1.7	1.1	17	14	16	140	m.i.
trichloroacetic acid	<0.1	1.2	1.1	12	13	10	280	m.i.
Others[4]	bdl	bdl	3.3	bdl	bdl	5.5	m.i.	m.i.

[1] Finished water
[2] Concentrated NaOCl stream
[3] Estimated
[4] Others include monochloroacetic acid, monobromoacetic acid, dibromoacetic acid.

m.i. Matrix interference
** No data available
bdl Below detection limit

Furthermore, ARCADIS conducted simulated distribution system (SDS) testing to determine the extent to which disinfection byproducts would be formed using effluent from the ClorTec T-12 system and dosing it with additional NaOCl. Six 1-liter effluent samples were collected, pH-adjusted to 8.5, spiked with NaOCl (at 2 mg/L and 4 mg/L dosing rates) and incubated for 24 hours at 20 °C. In addition, an SJWD finished water sample and a deionized water sample were collected, spiked, and incubated. Lastly, a sample of ClorTec finished water was incubated with no additional NaOCl added. After incubation, the six ClorTec samples were analyzed again for residual chlorine. A 2 mg/L-dosed sample and a 4 mg/L-dosed sample which contained 1 mg/L ± 0.1 mg/L residual chlorine were selected for shipment to the analytical laboratory along with the deionized water and SJWD finished water samples, and the unamended ClorTec T-12 finished water sample.

The results of the SDS testing are presented in Table 4-12. Testing included analyses for TTHMs and HAAs. A deionized water blank dosed with ClorTec T-12 NaOCl to achieve a calculated NaOCl concentration of 2 mg/L was submitted along with two ClorTec T-12 effluent samples. One of the ClorTec T-12 samples was dosed to achieve a calculated NaOCl concentration of 2 mg/L. The second ClorTec T-12 sample was dosed to achieve a calculated NaOCl concentration of 4 mg/L. Lastly, a sample of ClorTec T-12 effluent with no additional NaOCl added was submitted for analysis to determine the concentrations of DBPs formed during the prior disinfection process.

Minimal DBPs were detected in the deionized water blank (see Table 4-12). Comparable concentrations of the TTHMs bromodochloromethane, chloroform, and dibromochloromethane were detected in the samples dosed to achieve calculated NaOCl concentrations of 2 and 4 mg/L. Comparable concentrations of the haloacetic acids bromochloroacetic acid, dichloroacetic acid, and trichloroacetic acid were detected in the samples dosed to achieve calculated NaOCl concentrations of 2 and 4 mg/L. Monochloroacetic acid was also formed in samples dosed with both concentrations of NaOCl. More monochloroacetic acid was formed in the sample dosed to achieve 2 mg/L-calculated NaOCl than the sample dosed to achieve 4 mg/L-calculated NaOCl. The analytical results for undosed ClorTec T-12 effluent reveal that DBPs were formed during the initial disinfection process. This result is expected, as the ClorTec T-12 verification system

was not designed to remove organic compounds from the raw water as occurs in at many drinking water treatment plants. Subtraction of the DBPs quantified in the undosed effluent sample from the DBPs found in the dosed samples reveals that dosing to establish a residual chlorine concentration in a manner designed to simulate residual chlorine found in a drinking water distribution system resulted in the formation of significant additional DBPs. This is not unexpected since the ClorTec T-12 verification system was not designed to remove organic compounds from the raw water as occurs in at many drinking water treatment plants.

Table 4-12. Simulated Distribution System Test Results

	Deionized Water	SJWD Finished Water	ClorTec T-12 Finished Water	ClorTec T-12 Finished Water	ClorTec T-12 Finished Water
Quantity of ClorTec T-12 NaOCl Added	2 mg/L Additional NaOCl Added	No Additional NaOCl Added	No Additional NaOCl Added	2 mg/L Additional NaOCl Added	4 mg/L Additional NaOCl Added
Free Chlorine (mg/L)	1.4	0.8	0.5	2.0	3.0
Total Trihalomethane Analytes					
Bromodochloromethane (µg/L)	< 0.1	7.4	6.0	8.3	8.3
Bromoform (µg/L)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Chloroform (µg/L)	0.8	51	46	64	70
Dibromochloromethane (µg/L)	< 0.1	0.8	0.6	0.7	0.7
Haloacetic Acid Analytes					
Bromochloroacetic acid (µg/L)	< 1.0	4.2	2.7	4.0	3.7
Dibromoacetic acid (µg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Dichloroacetic acid (µg/L)	4.1	37	26	42	40
Monobromoacetic acid (µg/L)	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Monochloroacetic acid (µg/L)	< 2.0	3.6	4.3	16	4.0
Trichloroacetic acid (µg/L)	2.4	34	16	34	39

Chapter 5
Quality Assurance

5.1 Calculation of DQI Goals

Table 5-1 shows the data quality indicator (DQI) goals established for accuracy and precision presented in the ClorTec FOD. The calculated DQIs for the ClorTec demonstration are presented in Table 5-2. These DQIs were calculated using data from replicate analysis of laboratory or field QA/QC checks for each parameter. Obtained values represent the average of all replicate measurements. The number of replicates for each parameter is shown in parentheses. Accuracy was assessed by calculating recovery of spikes or surrogates or by calculating the bias from an obtained value compared to a known standard. Precision is expressed as percent relative standard deviation (RSD) and is calculated by dividing the standard deviation of replicate measurements by the mean. The 95 percent confidence intervals have also been calculated for data sets that contained at least three replicate measurements. It can be seen in Table 5-2 that DQI goals were met for chlorate/chlorite, iron, ammonia-nitrogen, sodium, TDS, total organic carbon, manganese, pH, free chlorine, and turbidity measurements.

Table 5-1. Data Quality Indicator Goals for Critical Measurements

Parameter	Method	Accuracy	Precision (%RPD)
Flow Rates	Flow controllers	± 2 ml/minute	N/A
pH	SM 4500 H	± 0.1 pH unit	Not listed
Temperature	SM 2550B	N/A	10
Raw Water Turbidity	SM 2130B	80-120% Rec.	25
Chlorine Residual	SM 4500-Cl F	N/A	40
Hydrogen sulfide	SM 4500-S2-A4c	90-110% Rec.	40
Alkalinity	SM 2320B	75-120% Rec.	30
Total dissolved solids	SM 2540C	80-120% Rec.	25
Ammonia-N	SM 4500-NH3 G	80-120% Rec.	25
Total organic carbon	SM 5310C	80-120% Rec.	25
Color	SM 2120B	N/A	40
Iron	EPA Method 200.7	85-115% Rec.	20
Manganese	EPA Method 200.7	85-115% Rec.	20
Chloride	EPA Method 300	90-110% Rec.	30
Sodium	EPA Method 200.7	85-115% Rec.	20
Potassium	EPA Method 200.7	85-115% Rec.	20
Total coliform	SM 9222B	N/A	200
HPC bacteria	SM 9215B	N/A	N/A
TTHMs	EPA Method 524.2	70-130% Rec.	40
HAAs	EPA Method 552.1	70-130%	40
Chlorite/Chlorate	EPA Method 300 B	90-110% Rec.	30

Table 5-2. Calculated DQIs for Critical Measurements

Analyte	Actual Conc.	Avg. Obtained (# points)	Recovery/Bias* (Average %)	Precision (%RSD)	95% Conf. Interval
Chloride	25 ug/L	24.3 (3)	97.2	3.2	1.94
Chlorate/Chlorite	100 ug/L	94.7 (5)	94.7	2.0	2.91
Bromide	100 ug/L	97.4 (1)	97.4	N/A	N/A
Iron	1 mg/L	1.01 (7)	101	5.0	0.045
Ammonia-N	5 mg/L	4.83 (4)	96.6	3.1	0.23
Sodium	1 mg/L	1.02 (3)	102	1.5	0.04
Total Dissolved Solids	451 mg/L	458 (1)	102	N/A	N/A
	467.5 mg/L	465 (2)	99.5	N/A	N/A
Total Organic Carbon	10 mg/L	9.93 (5)	99.3	0.9	0.12
Manganese	50 ug/L	50.9 (3)	101.6	6.3	7.9
pH	4.0	4.01 (47)	0.25*	0.3	0.004
	7.0	7.0 (47)	0*	0.1	0.003
	10	10.01 (47)	0.1*	0.07	0.002
Free Chlorine	0.5 mg/L	0.47 (85)	6.0*	7.2	0.007
	1.0 mg/L	0.94 (88)	6.0*	4.1	0.008
	2.0 mg/L	1.7 (7)	15.0*	20	0.32
Turbidity	1.35 NTU	1.35 (72)	0*	0.2	0.0006
	16.4 NTU	16.4 (72)	0*	0.1	0.004
	150 NTU	149.4 (72)	0.4*	0.4	0.14
	2147 NTU	2149 (72)	0.1*	0.2	0.75

* - indicates that the result is “Bias”

Table 5-3 presents the TTHM recovery results from surrogates spiked by EHL prior to sample analysis by EPA Method 524.2. The surrogate standards are purchased by EHL from AccuStandard, Inc. Representative Certificates of Analysis for the surrogate standards have been provided by EHL and are included in Appendix B. Acceptance criteria established in the method is 70-130 percent. It can be seen that all compounds met the acceptance criteria except bromoform, which slightly exceeded 130 percent recovery on two out of five analyses.

Table 5-3. Trihalomethane Recoveries (70-130% criteria)

	Spiked Conc.	Bromodichloromethane		Bromoform		Chloroform		Dibromochloromethane	
Date	(ug/L)	Obtained	%Rec	Obtained	%Rec	Obtained	%Rec	Obtained	%Rec
3/27	5	5.78	116	6.74	135	5.75	115	5.91	118
3/27	10	11.9	112	12.89	129	11.13	111	11.22	112
3/28	10	12.41	124	14.18	142	12.37	124	12.51	125
4/27	10	9.5	95	8.62	86.2	8.92	89.2	9.57	95.7
5/10	10	10.58	106	10.21	102	10.32	103	11.03	110

Table 5-4 shows the HAA recoveries of a 20 ug/L standard analyzed by EPA Method 552.2. Acceptance criteria are established as 70-130 percent. All compounds fell within the acceptance criteria for this analysis.

Table 5-4. Haloacetic Acid Recoveries for 20 ug/L Standard (70-130% criteria)

Sample Date	Bromochloro Acetic Acid		Dibromo Acetic Acid		Dichloro Acetic Acid	
	Obtained	%Rec	Obtained	%Rec	Obtained	%Rec
3/24	22.12	111	25.82	129	21.82	109
4/28	21.01	105	21.51	108	19.59	98
5/12	18.36	92	19.52	98	20.13	101

Sample Date	Monobromo Acetic Acid		Monochloro Acetic Acid		Trichloro Acetic Acid	
	Obtained	%Rec	Obtained	%Rec	Obtained	%Rec
3/24	18.06	90.3	15.96	79.8	19.83	99.2
4/28	17.39	87	15.63	78	17.78	89
5/12	18.18	91	22	110	18.11	91

5.2 Blanks, Duplicates and Hold Times

Blank samples were routinely sent to the laboratories with each set of samples for analysis. Each laboratory also ran internal laboratory and reagent blanks as a part of their daily QA/QC procedures. Results from analysis of field and laboratory blanks did not indicate contamination problems for any analyte of interest in this study.

A total of six duplicate free chlorine samples were conducted at SJWD. The percent difference for these free chlorine duplicate analyses varied from 0% to 32%. The 32% difference was measured during the analysis of a routine 0.5 ppm calibration standard. Analysis of subsequent standards at 1 ppm and 2 ppm resulted in 6% and 42% difference values respectively. A total of three total duplicate total chlorine analyses were conducted at SJWD. The percent difference for these total chlorine duplicate analyses varied from 0% and 2%. For total Coliform counts routine samples taken by SJWD were used as duplicates. SJWD samples were taken from the same raw water intake where water for the ETV test were taken. During the test, Coliform samples for both SJWD and ETV were collected by the same person around the same time. ARCADIS chose four dates randomly and compared the counts. Total Coliform counts for the SJWD routine samples ("duplicates") for these dates were 300, 800, 200, and 800 CFU/mL, whereas those for the ETV raw water samples were 350, 1500, 100, and 750 CFU/mL.

Duplicate samples of EHL analytical parameters including manganese, chloride, TTHMs, HAAs, color, TDS, iron, sodium, ammonia, TOC, and UV 254 were shipped to EHL on May 4, 2000. The resulting data can be found in Appendix B in EHL Report # 491349-92. The duplicate parameters are labeled "Out 1" and "Out 2" in the set of results. Generally, there was excellent agreement between the duplicate samples.

Hold times specified in the methods were met for all samples with the following exception: sample numbers 478714 and 478717 for true color analysis. These samples were collected on 3/17/00 and analyzed on 3/20/00, which exceeded the 48-hour hold time specified in the method. The laboratory informed the Project Manager that the hold time would be exceeded and was instructed to analyze the sample as soon as possible. The 48-hour hold time for true color analysis was exceeded by 24 hours or less.

5.3 Daily and Bi-Weekly QA/QC Verifications

As indicated in the FOD, certain parameters associated with verification testing required daily or bi-weekly verification. The flow rate of the sodium hypochlorite dosing pump and finished water flow to the turbidimeter were verified daily using a timed, volumetric collection method. This data can be found in Appendix B. In-line turbidimeter readings were compared on a daily basis to readings from a calibrated bench-top turbidimeter and record on the data sheets in Appendix B. References to in-line rotameter maintenance and flow verification and in-line turbidimeter maintenance can be found in the bound project notebook presented as Appendix A. Tubing and piping were visually inspected on a daily basis and found in order.

5.4 Internal Audits

Dr. Jane McLamarrah of ARCADIS performed an internal technical systems audit at the demonstration site on May 5, 2000. Results from the audit were reported to the ARCADIS Project Manager in an audit report, which is included in Appendix C. An internal data quality assessment was done on the raw field and laboratory data. QA/QC data supplied by the field crew and contract laboratories was reviewed and data quality indicators including accuracy and precision were calculated. Calibration curves were reviewed and calculation verified for at least 10 percent of all the analytical data. Laura Beach, ARCADIS QA Manager/Durham Office, performed this assessment.

Chapter 6
References

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